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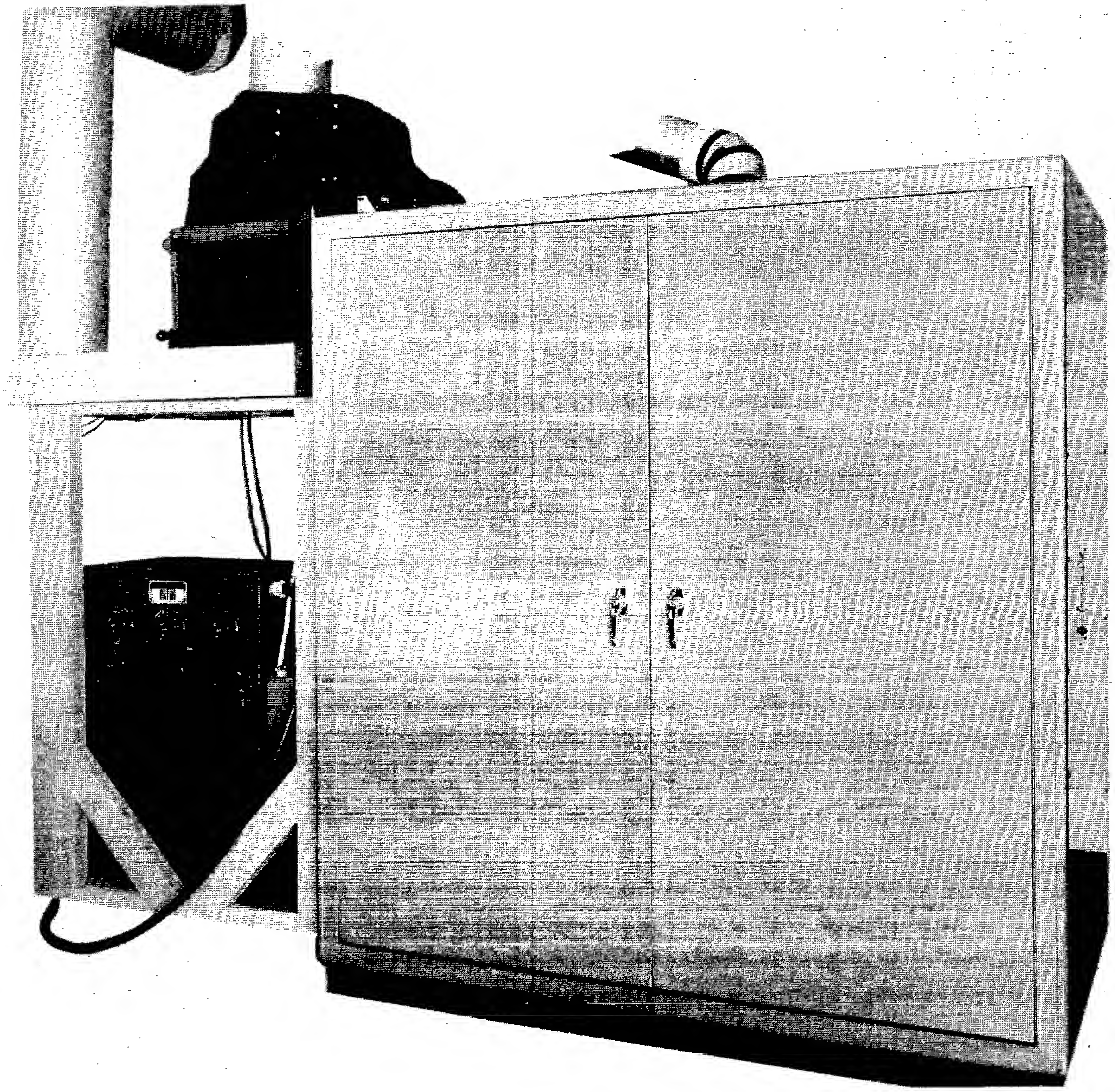
List of Illustrations

List of Illustrations (cont.)

I. INTRODUCTION

An Image Processor has been designed and built as a portion of a coherent high resolution radar system. This unit is an optical device designed for use in a laboratory on the ground, see Figures 1 through 4. A separate chemical processor is used to develop the data and map films. The Processor accepts the (unintelligible) data, see Figures 5 and 6, from the airborne equipment and converts it to a radar map as shown in Figures 7 and 8.

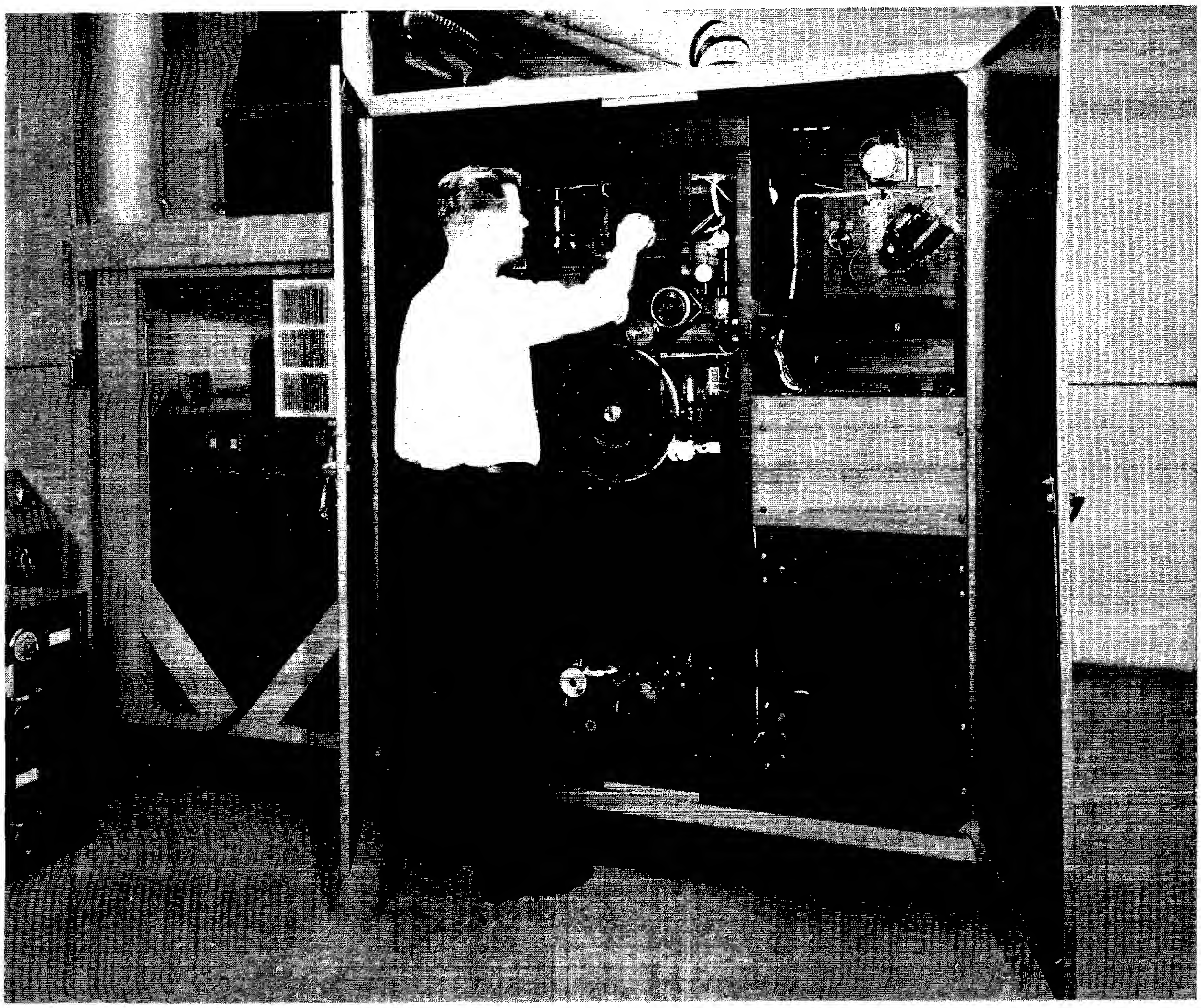
This report gives a brief history of the project, presents the basic theory and requirements of the optical system, and describes the processor's optical and mechanical systems. The performance is discussed in section V and the many phases of the project other than the processor are listed in section VI.



9015 PROCESSOR

The carbon arc is on the left, the cabinet houses the optical unit including film drives and controls. The main control panel is at the right.

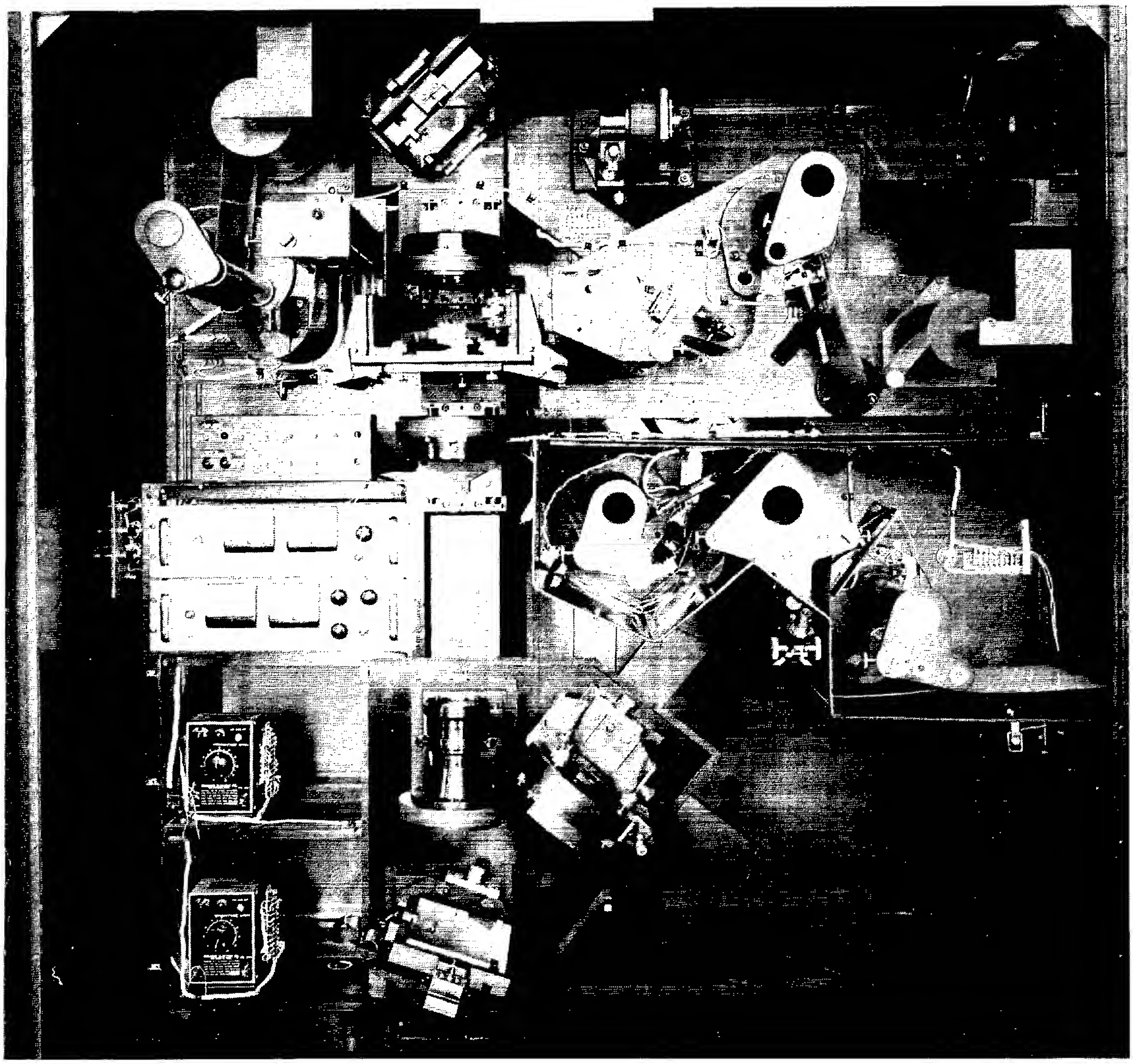
Figure 1



INTERIOR OF PROCESSOR (REAR)

The operator is adjusting the data illumination. The main film drive is below his arm, the electrical equipment is at the right.

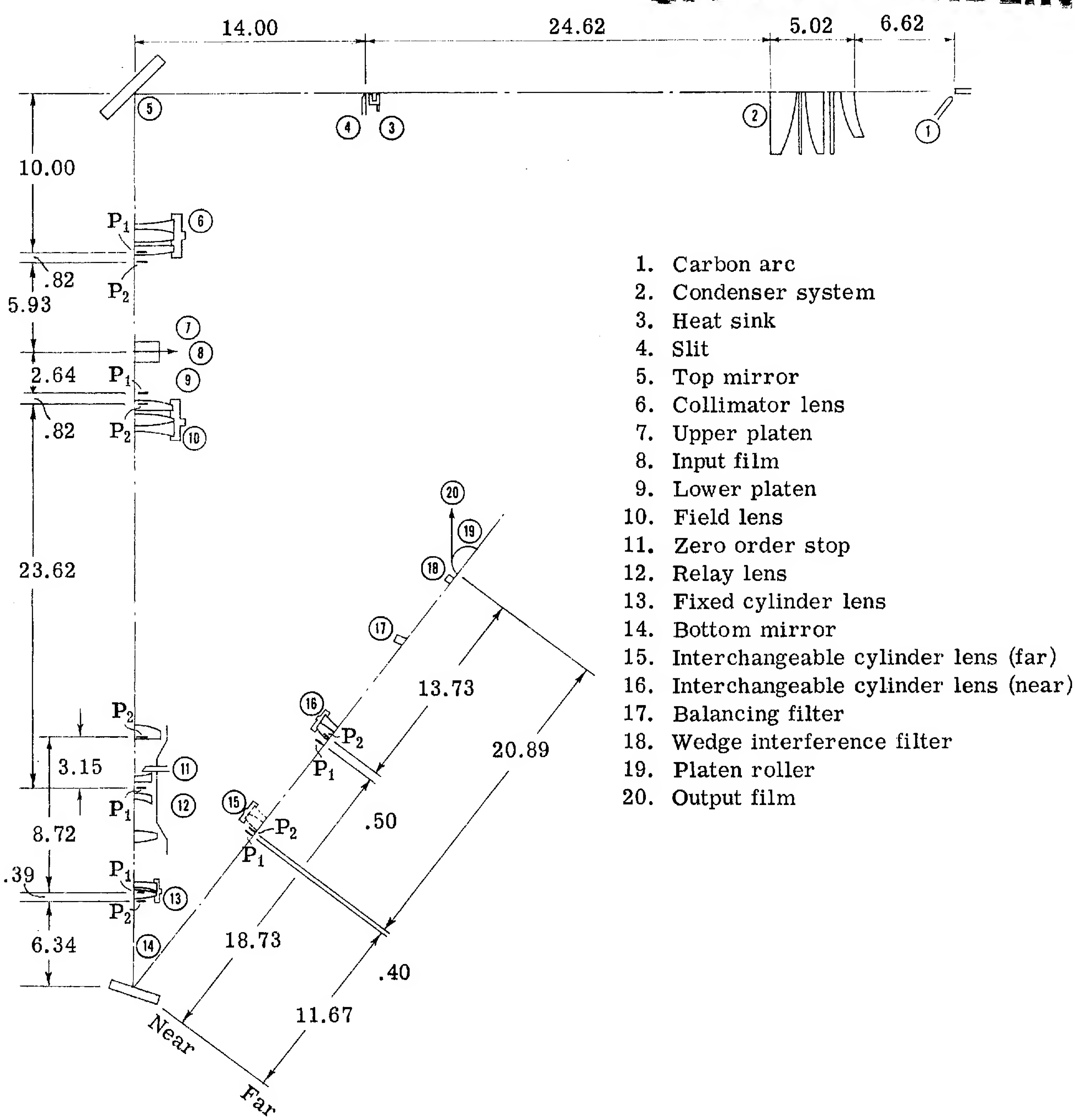
Figure 2



INTERIOR OF PROCESSOR (FRONT)

The optical parts can be identified from Figure 4. The input film runs from the spool at the upper left to the take-up spool at the right. The output map film runs from the lower film magazine (mounted externally) to the left, then back to the upper take-up magazine. (Some parts have been added or modified since this photo was taken.)

Figure 3



OPTICAL SCHEMATIC

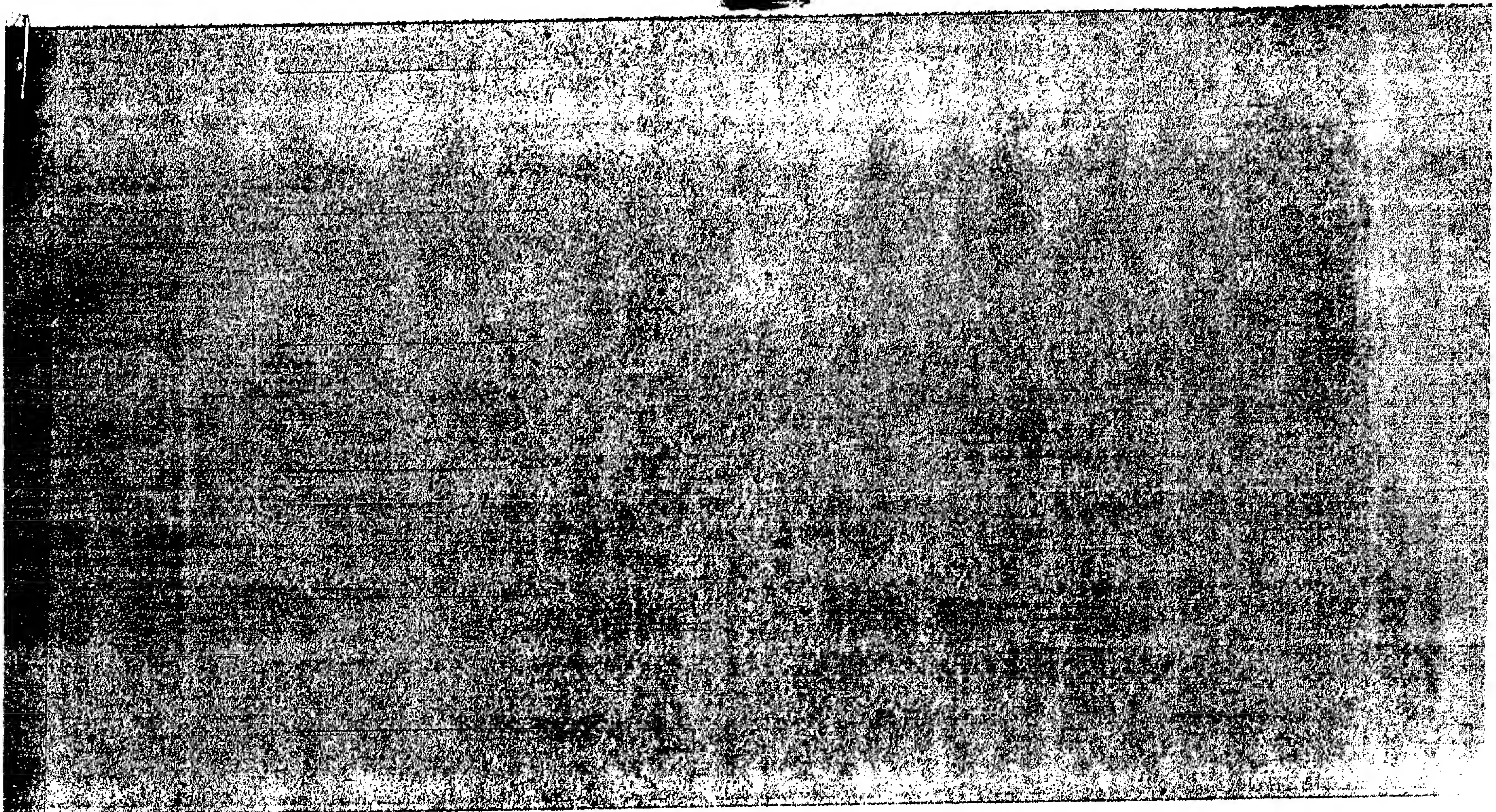
Figure 4

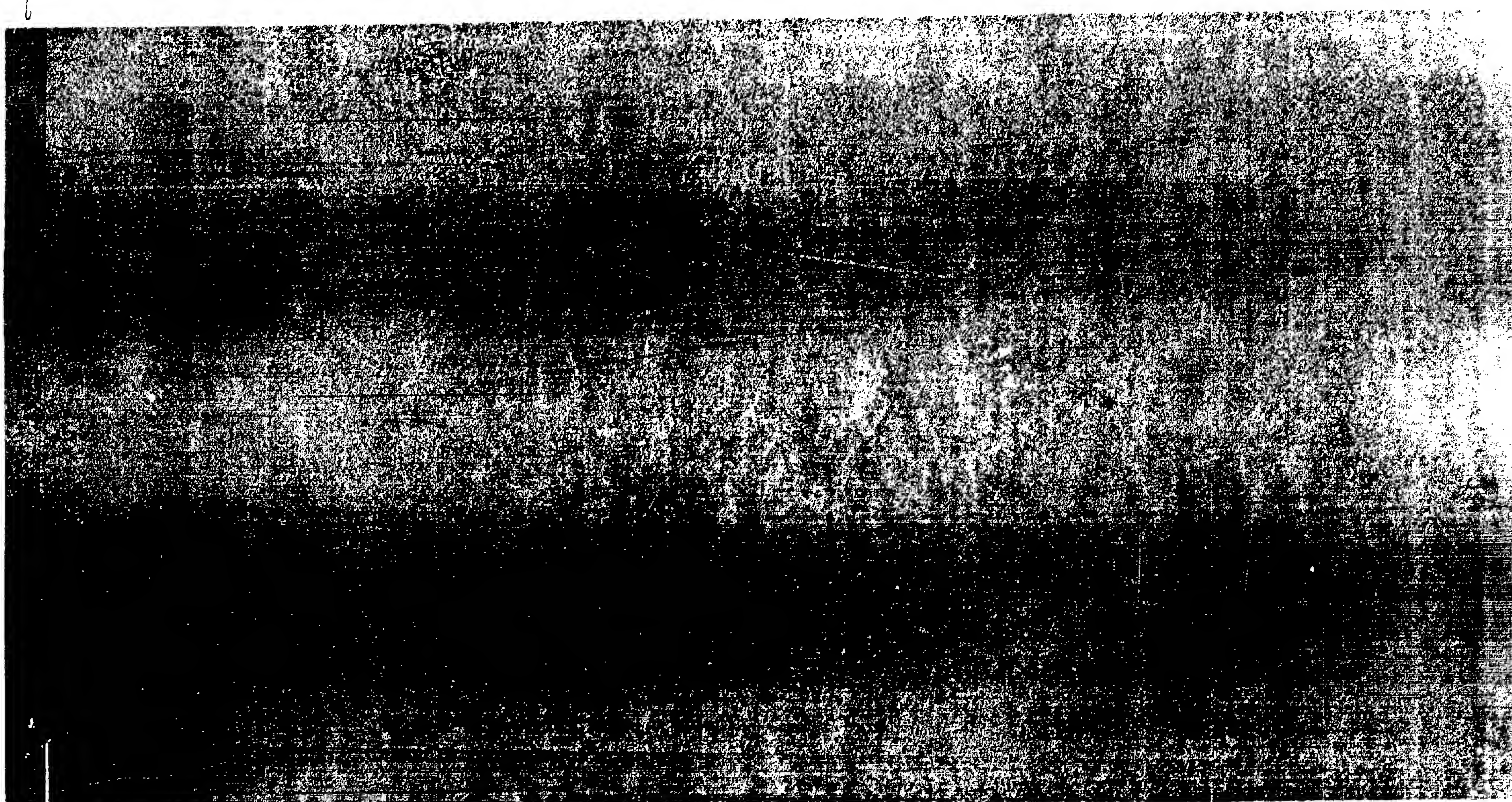
This is a positive duplicate of a section of the film from flight S87.

Note: In order to display a good example of the Flight Film data and also give a good impression of the format, the data blocks from run S-93 have been dubbed onto the S87 film (the data flash was turned off in the S80 series, the S90 series is a shake-down of a new radar set).

SAMPLE DATA (INPUT) FILM

Figure 5





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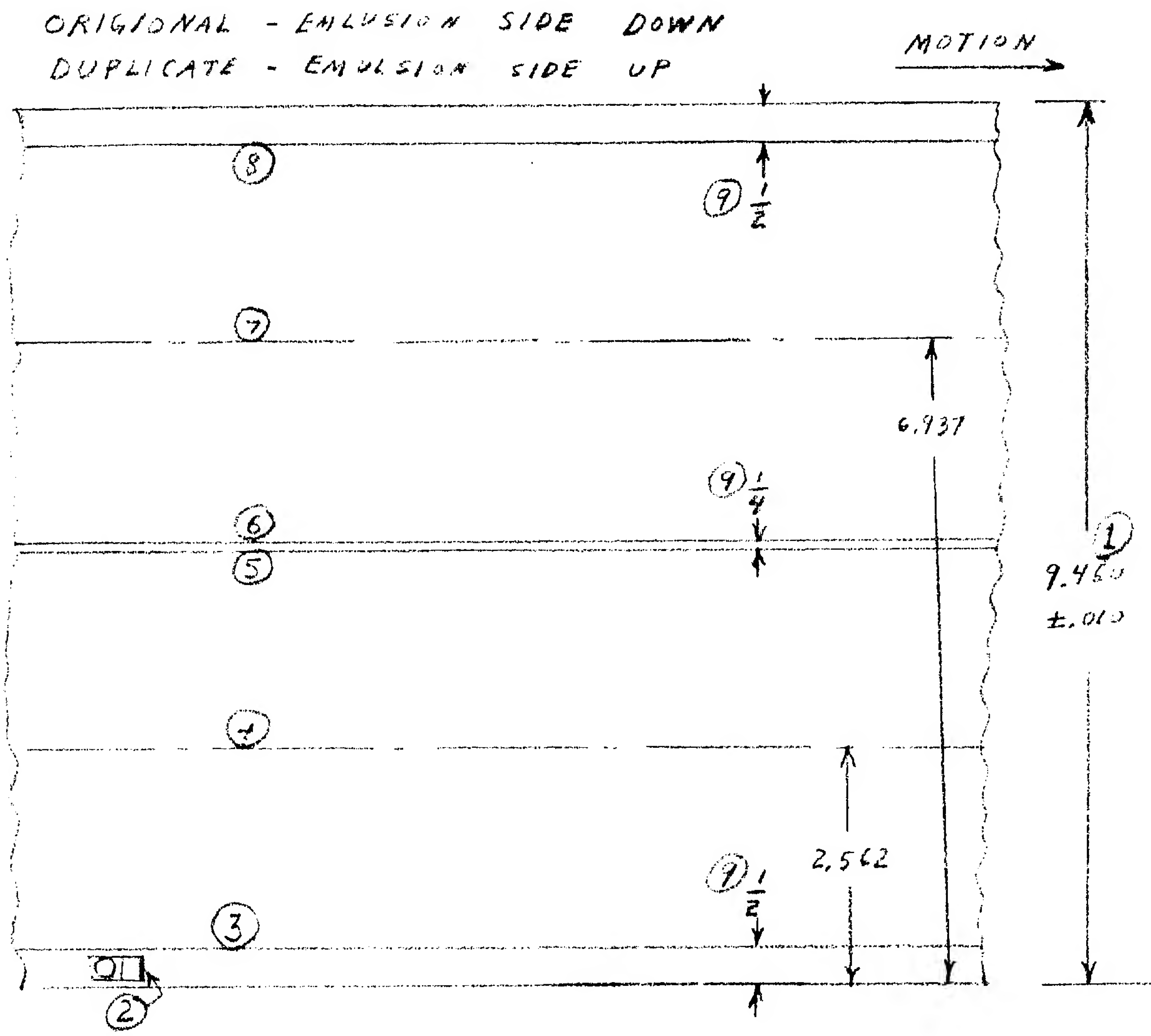


1. Film width per MIL-F-32A
2. Data blocks approximately 1/4" x 9/16", 10" apart
3. Start of near range trace
4. Defined center of near range
5. End of near range trace
6. Start of far range trace
7. Defined center of far range
8. End of far range trace
9. These values will vary somewhat due to the recorder alignment and usable CRT size.
10. The film is threaded into the processor with the data block in rear, motion toward right.

FORMAT OF DATA (INPUT) FILM FORMAT

Figure 6

The area shown is Martinsberg, West Virginia

North

The transparency is a second generation duplicate of S87-CN11, a map film made in the Processor from S87. The print (figure 7A) is a contact from the original S87-CN11. The map film has a wide latitude of exposures and hence low contrast. In practice 2 or 3 high contrast prints are required to show all the available targets from fields to buildings.

See note on Figure 5

SAMPLE MAP (OUTPUT) FILM

Figure 7

SPECIAL HANDLING

SPECIAL HANDLING

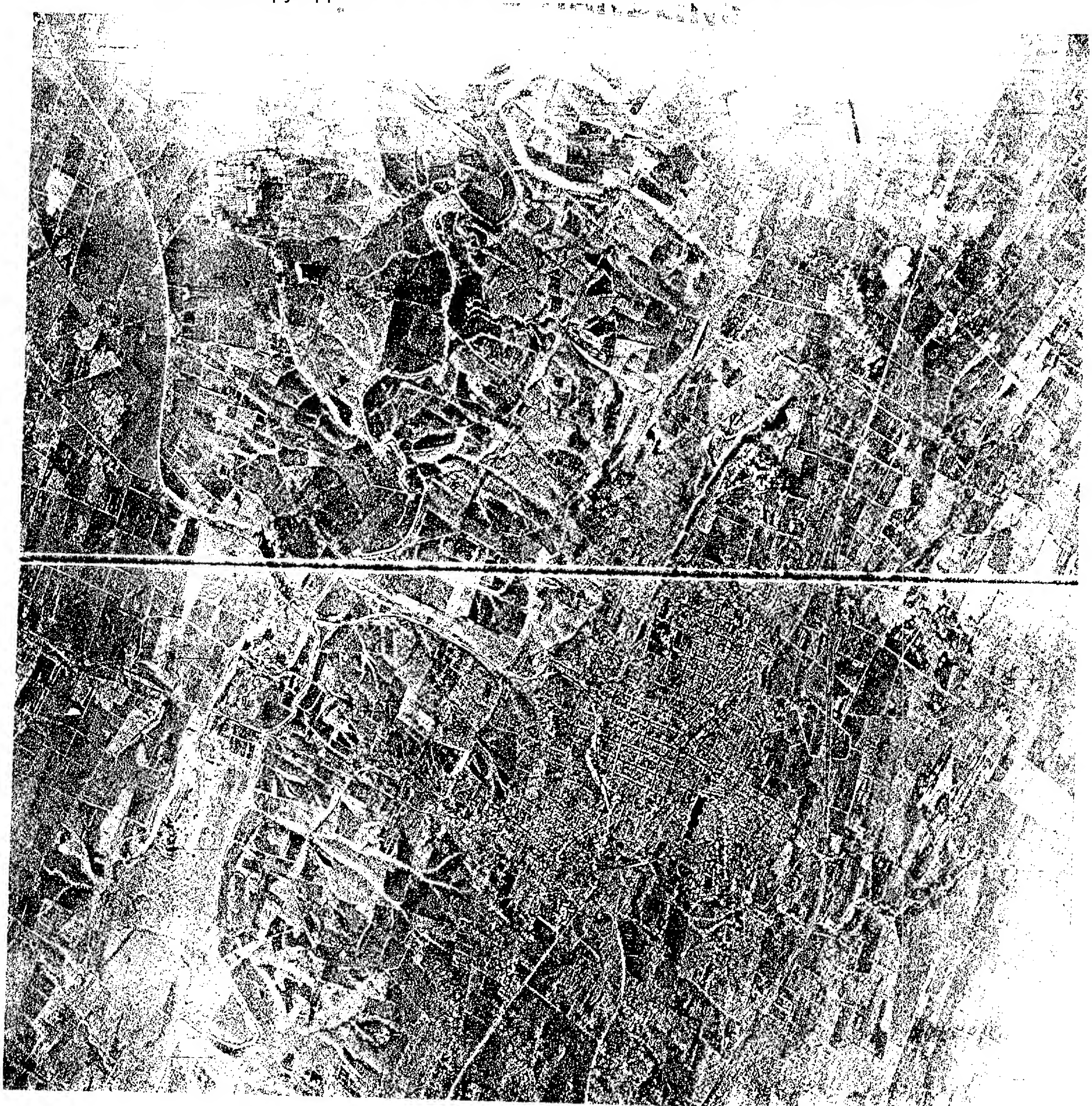
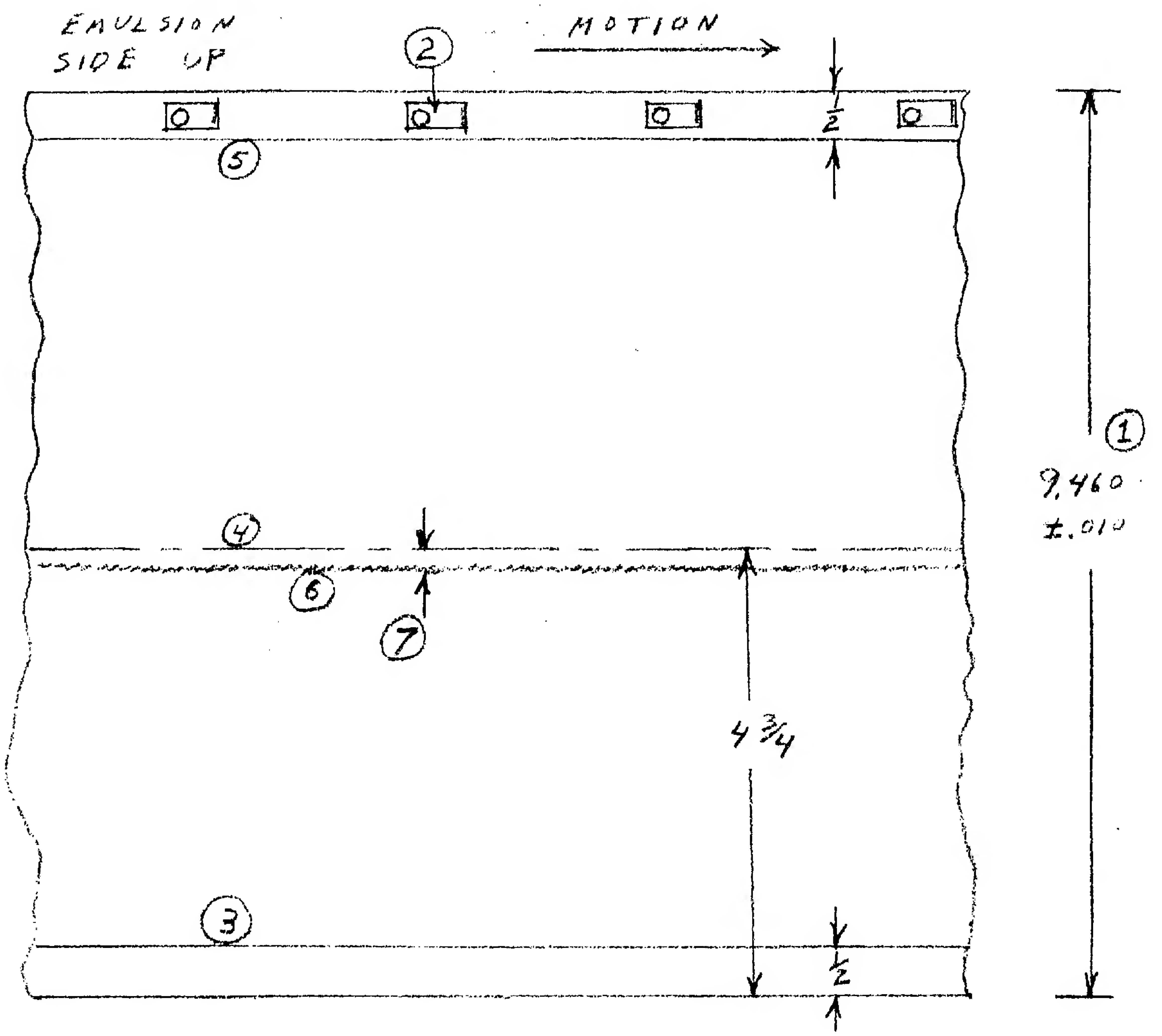


Figure 7A
Print of Figure 7



1. Film width per MIL-F-32A
2. Data block approximately 1/4" x 9/16" approximately 2 1/2" apart.
3. Start of trace (near or far range)
4. Center of trace (near or far range)
5. End of trace (near or far range)
6. Streak left by interference filter
   width of some image degradation approximately 3/32
   width of totally lost image approximately .005"
7. This depends on the adjustments made during operation. The nominal distance, based on Memo WJD17 (Appendix II) would be an offset of .190" (near range) and .357" (far range) in the direction shown.

FORMAT OF MAP (OUTPUT) FILM FORMAT

Figure 8

II. HISTORICAL DEVELOPMENT OF THE PROCESSOR

The project was discussed early in 1960. Itek contributed to the overall system proposal (the 6B proposal) which was submitted in August with a scheduled delivery in May 1961. This delivery date had been set early in 1960 on the basis of a 14-16 month program, and was not changed until the design was far enough along to obtain detailed schedules. This occurred in February 1961, when delivery was rescheduled for August 31, 1961.

A preliminary optical bench program was planned to provide data for the detailed design of the processor. This work was done during the Fall and Winter of 1960, but it was soon realized that the schedule did not allow ample time for the planned work, and also that the equipment and tests would require greater precision than planned. For this reason the design in the proposal was reanalyzed, checked for basic feasibility on the bench, and then used as the basis to proceed with the design of the Processor.

The system design, detailed design, drafting, and fabrication proceeded at great speed during the months of December 1960 to August 1961. A number of basic problems were recognized and given considerable attention. Many laboratory mock-up and breadboard versions of novel devices were built and tested in time to contribute to the final design.

The assembly proceeded smoothly during the summer of 1961 and it appeared that the processor would be complete (but not aligned or tested) by August 31. However, parts shortages, mechanical interferences, and electrical assembly time prevented completion until October.* In November 1961 the processor was functioning and some hand drawn simulated target patterns were used to demonstrate reconstruction during an acceptance test.

Late in 1961 it was ascertained that the Processor would stay at Itek for an extensive Test and Simulation program, further improvement of performance, completion of the data optics, and modifications to the optical system made necessary by system changes (ie the recorder speed).

The first months of 1962 were devoted to making performance tests on the original (24 inch) optical system, modifying the optics and film drive for the new pattern focal lengths (150 inch) and working on the film drives and liquid platen to obtain dependable operation. The optical and mechanical design for the permanent 150" system was carried out and parts ordered. The first flight films were received in March, and in May 1962 flight S11 produced a recognizable radar map.

By May most of the optical testing had proceeded to its limit with the original cylinder lenses. New lenses had been ordered for delivery

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* the data optics link was not completed at that time

in May, but the vendors had great difficulty meeting specifications, and we did not receive the good cylinder lenses until November. The Processor was used for the flight test support and some film drive and liquid platen problems were worked on.

The installation of the new cylinder lenses and ten inch wedge interference filter in the processor brought new effort to improve the performance tests results and the quality of the F101 flight test radar maps. This effort gained some immediate improvements, but its prime result was a clear delineation of some of the operational difficulties of experimenting on the processor. Throughout 1962 the testing and adjusting of the unit had been frustratingly slow, chiefly because of the complexity of the correlation technique, the design limitations of the processor,* the lack of good data film, some continuing problems with the liquid platen and film drives, and the need to continually be prepared to correlate flight film. The problems became more serious as the capability of the optical system improved and the tests became more exacting. A number of steps were taken in 1963 to solve some of these difficulties.

The period from November 1962 to December 1963 was devoted to continued testing and modifying of the processor along with the formulation of concepts for a second generation processor. All during 1963 it was expected that the processor would be shipped within one to three

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* The processor design was optimized for normal daily use, not testing and experimentation

months. Most of the modifications were designed so that they could be installed with a minimum of down time and at the site if necessary. The modifications included a 4 x 5 camera and viewing station (February), a TV viewing system (temporarily installed in March and completed in October), a new zero order stop in the relay lens (April), a new platen with film guides (July), a new film drive (August), and a new data optics system (December).

The testing program was implemented with the improvements to the processor, a new series of precision test target arrays, a full time photographic technician, a new microdensitometer,* and additional theoretical work.** The tests became more exacting and the data more dependable and complete. The on axis performance of the optics was found to be near the theoretical diffraction limit, and a field curvature problem was uncovered and measured (modifications to flatten the field are being studied).

Itek assumed responsibilities for the first phase of the field support. Steps were taken to insure adequate facilities, personnel, and procedures for that support. At the time of publication of this report, the processor is at the field site having been shipped on March 20, 1964.

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* Company owned
** Partly company sponsored

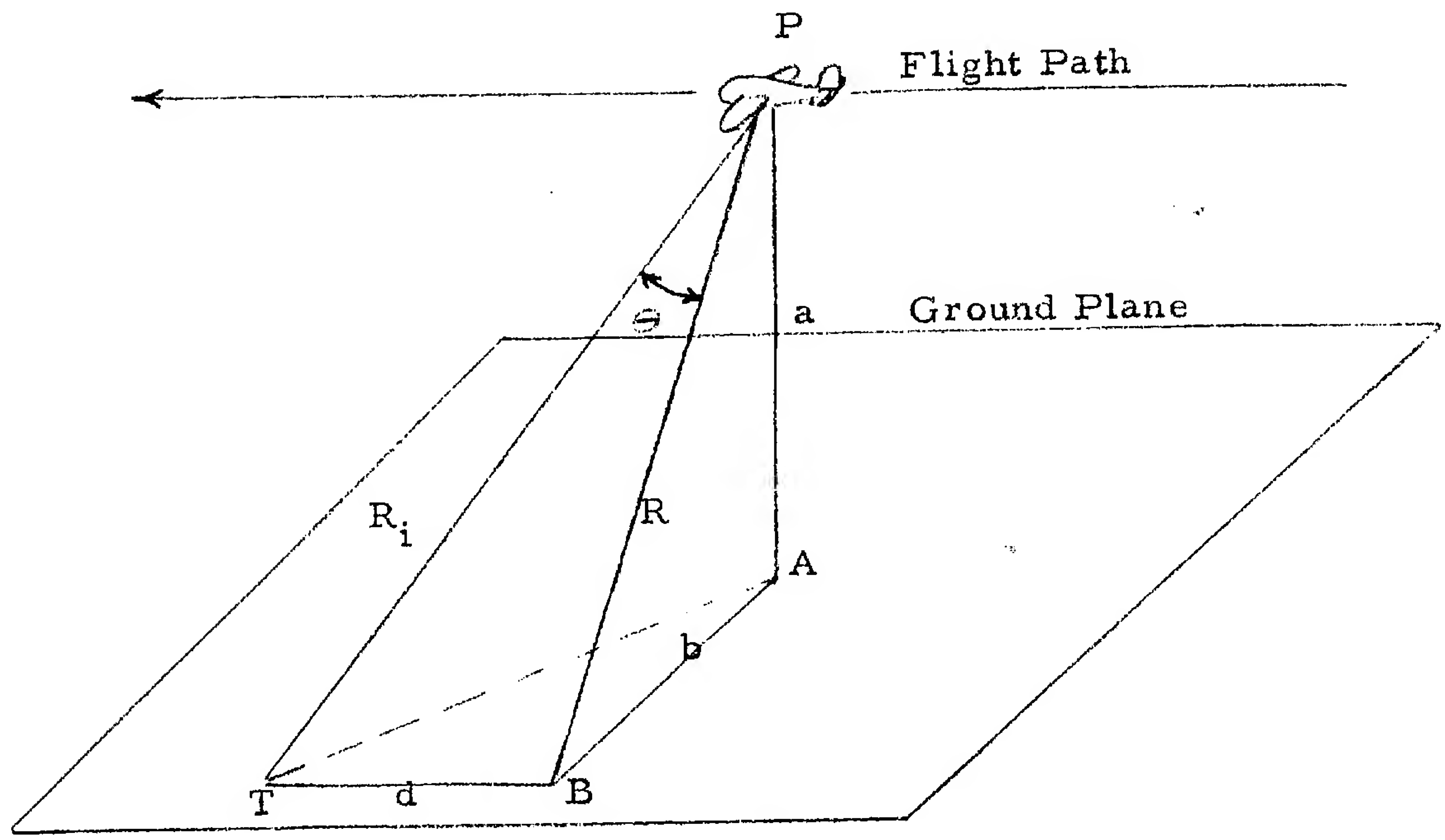
III. THEORY AND REQUIREMENTS

The processor is an integral part of a coherent radar system. The nature of the processor is dictated by the design of the radar as well as the operational requirements. For this reason, the processor requirements will be discussed in terms of the radar system as well as in terms of the input film.

This theory can be expanded at great length to investigate the many details involved. Some theoretical work was done on the project to obtain information about certain problems. A great deal of theoretical work has been done elsewhere, some of which is available in the Michigan Radar reports and other documents. The theory presented here only demonstrates the derivation of the focal length equation which described the nature of the data that must be processed.

The coherent side-looking radar is flown past the target and the phase as well as the amplitude of the return signal is used to modulate the cathode ray tube display. The CRT is photographed with a moving film camera (ie recorder) in which the film moves rapidly enough to resolve the fine structure due to the phase changes. The geometry of the pattern thus produced can be obtained by referring to Figure 9 and realizing that the phase of the return is

$$\phi = \frac{2R_i}{\lambda_r}$$



a altitude

b offset ground range

d distance of target from abreast position

R_i instantaneous slant range

R offset slant range

θ angle between the normal to the flight path and the target

GEOMETRY IN RADAR STAGE

Figure 9

From the geometry, R_i can be stated in terms of the constant distance R from the flight path to the target and the varying distance d along the flight line

$$R_i = \sqrt{R^2 + d^2}$$

This can be expanded as

$$R_i = R + \frac{1}{2}\frac{d^2}{R} - \frac{d^4}{8R^3} + \ldots\ldots\ldots\ldots$$

The higher order terms can be dropped so that

$$\phi = \frac{d^2}{\lambda_r R} + \phi_o$$

where ϕ_o is the phase at d = o. The intensity of the CRT is

$$I = A_o + A \cos \phi$$

where A_o is a bias level and A is the strength of the return signal. The film is moved past the CRT at a velocity v while the aircraft moves at a velocity V.

A distance d' on the film corresponds to the distance d by the equation

$$d' = \frac{v}{V} d$$

and

$$\phi = \left(\frac{V}{v}\right)^2 \frac{d'^2}{\lambda_r R} + \phi$$

Thus a transmission pattern is exposed onto the film such that

$$T = T_o + T \cos \phi$$

$$= T_o + T \cos \left(\frac{V}{v}\right)^2 \frac{d'^2}{\lambda_r R}$$

The pattern is shown in Figure 10, except that in the figure the cosine variation is approximated by a square wave.

This transmission pattern is used to modulate the plane wavefront of light in the correlator. The pattern acts as an optical zone plate and focusses the light to a point at a distance f (the zone plate focal length) of

$$f = \frac{a^2}{\lambda}$$

where a is the distance out to the first half cycle and λ is the optical wavelength.

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TYPICAL PATTERN

This is a copy of a ruled test pattern. It would represent a target elongated in range

Figure 10

The value of a is the value of d' when $\phi = \frac{1}{2}$, thus

$$\left(\frac{V}{v}\right)^2 \frac{a^2}{\lambda_r R} = \frac{1}{2}$$

or $$f = \frac{1}{2}\left(\frac{v}{V}\right)^2 \frac{\lambda_r R}{\lambda}$$

Thus, the fine structure in the recorded signal gives rise to a lens (zone plate) effect in the processor. The processor is designed to utilize this effect and reconstruct the image. The focal length varies with range R of the target, so the processor must be designed to compensate for this variation. In the present unit, this is done by making the wavelength λ vary linearly with distance across the film so that

$$\lambda = kR$$

Many of the detailed requirements and inter-relationships between the radar parameter and processor for the F101 and final vehicle test program have been worked out in two memos. These are included in Appendix II.

The range variation encountered in practice is many hundreds of wavelengths (each wavelength gives rise to one peak in the pattern), but is only a few range resolution elements wide. If the beam points directly

broadside (as in the case for the F101 test flights) the variation is less than one resolution element and can be ignored. If the beam points ahead (or behind) the range change will give rise to a rotation of the image, which required that the input slit and cylinder lenses in the system must be rotated to correspond. In the range direction, the processor merely relays the data image onto the output film as if it were a standard enlarger. In the present processor this is done at a magnification of 2X.

Inputs and Outputs

The input film is 9 1/2" wide and up to 500 ft. long. It will have been chemically processed and will contain photographic data according to the format shown in Figure 6. The focal length of the patterns will be approximately 150 inches (using λ = 550 millimicrons) on the center of the near range, and 200 inches for the far range.

The output will be on two 9 1/2" wide films, each shorter than the input by a factor of 4.37. The format is shown in Figure 8. The map scale factors depend on many parameters, but for the F101 tests the scale is approximately 1.2 n miles per inch in azimuth and .53 to .66 n miles per inch in range (the scale varies with range). For the final system the scale factors will be approximately 1.17 n miles per inch in azimuth and .9 to 1.2 n miles in range (see Appendix II). The final resolution anticipated is on the order of 20 to 30 ft. ground resolution, ie spot diameters of .003"

to .004 ". The map film will be a negative and can be printed in the usual fashion to make positive prints. If a contact print of the original data film is used as the input, the map film will still be a negative. The recommended film is Royal X Pan Recording Film, although any panchromatic film could be used.

Operational Requirements

The processor is ground based equipment and can have any reasonable size, weight, and environment requirements. The actual processor including carbon arc is 8 feet high, 8 feet long, and 4 feet wide, and weighs about 3,000 pounds. It is designed to operate in a clean, air conditioned room typical of a modern office. It is expected that it will be run by one technician.*

The performance of the processor cannot be simply specified separate from the rest of the system. The specification requests "no serious degradation" in the reconstruction process. This subject is discussed in section V.

The resolution requirement for the data optics system is "adequate", a design goal of 20 lines per mm referred to the data film has been established.

* Although the processor is not dangerous (there have been no accidents in 2 years of operation) the motorized drive and carbon arc would indicate that safety requirements might indicate that two people be available at all times.

IV DESCRIPTION OF THE PROCESSOR

A. General

The processor was built on a sturdy frame with the 13 foot long optical path folded to place the input and output film drives in close proximity. The unit was housed in a large cabinet to give ample room to work and add modifications if necessary (refer to Figures 1 to 3). The carbon arc was mounted separately to provide for vibration isolation and ease of changing to smaller light sources if feasible.

The philosophy of the design was to provide for a rugged, dependable unit with a minimum of interdependent complexities. Ease and flexibility of operation as well as accessibility were design goals but were of lower priority than dependability of the design. For example, the rollers in the film drives were mounted for maximum precision and stability, and the ability to thread in the middle of the roll was thereby sacrificed. This philosphy worked very well in many respects (such as the optical mounts) but it caused inflexibilities which created considerable trouble in the areas where the original design was inadequate and required extensive development work (such as the input film tracking).

B. Main Optical System

The design of the optical system was based upon the use of small relative apertures and small field angles so as to simplify the lenses

and minimize any problems due to skew rays. This dictated the long optical path (about 13 feet) and hence a large unit.

The optical schematic is shown in Figure 4. The carbon arc is focused onto the input slit (5 to 40 μ wide). The collimator forms the plane wavefront to strike the data film and the field lens refocusses the beam onto the zero order stop. This opague baffle stops all the light except that diffracted into the real image by the zone plate pattern. A pattern in the platen will have formed a diffraction image at a distance of 150 inches (or 200 inches). This is reimaged by the field lens to a point about 2 inches from the zero order stop. The cylinder lenses refocus it onto the output platen. In the original design (for the 24" focal length patterns) one cylinder lens was used but two lenses are required for the 150" patterns to avoid mechanical interference with the mirror.

The wedge interference filter which selects the wavelength for each range must be located at or near a range focus. This occurs at the input platen and again at the output platen. The original design used a filter at the input platen, but the 150" targets demanded a 3 inch wide filter, which could not be fabricated. The filter was shifted to the output, where the width requirement is less than 1/2 inch. Unfortunately, the vendor had to make the 9 inch length by butting two 5 inch filters, which leaves a streak down the center of the output film (see Figure 7). This can be eliminated whenever the vendor obtains suitable equipment.

The optical system in the range direction is an enlarger which uses the relay lens to magnify the range by a factor of 2. This magnification was originally chosen on the basis of using Plus X as the optimum film for achieving adequate resolution with the highest operating speed.

The exit slit is not critical, and merely limits the width of field used. The optical system forms an image about one half inch wide, the slit is usually set .100 inch wide. The width of the slit can be shaped to give a uniform exposure across the field if desired.

All of the optics in the system were designed at Itek. The final designs were done for the entire system, that is, the thickness of the platens and presence of field lenses were included in the abberation calculations. The individual lenses have a poor performance when not used in the system which has led to some difficulty in component testing. Unfortunately, the computer programs then available could not handle skew rays in cylinder lenses, and two subtle problems in the lens design were not discovered until recently.

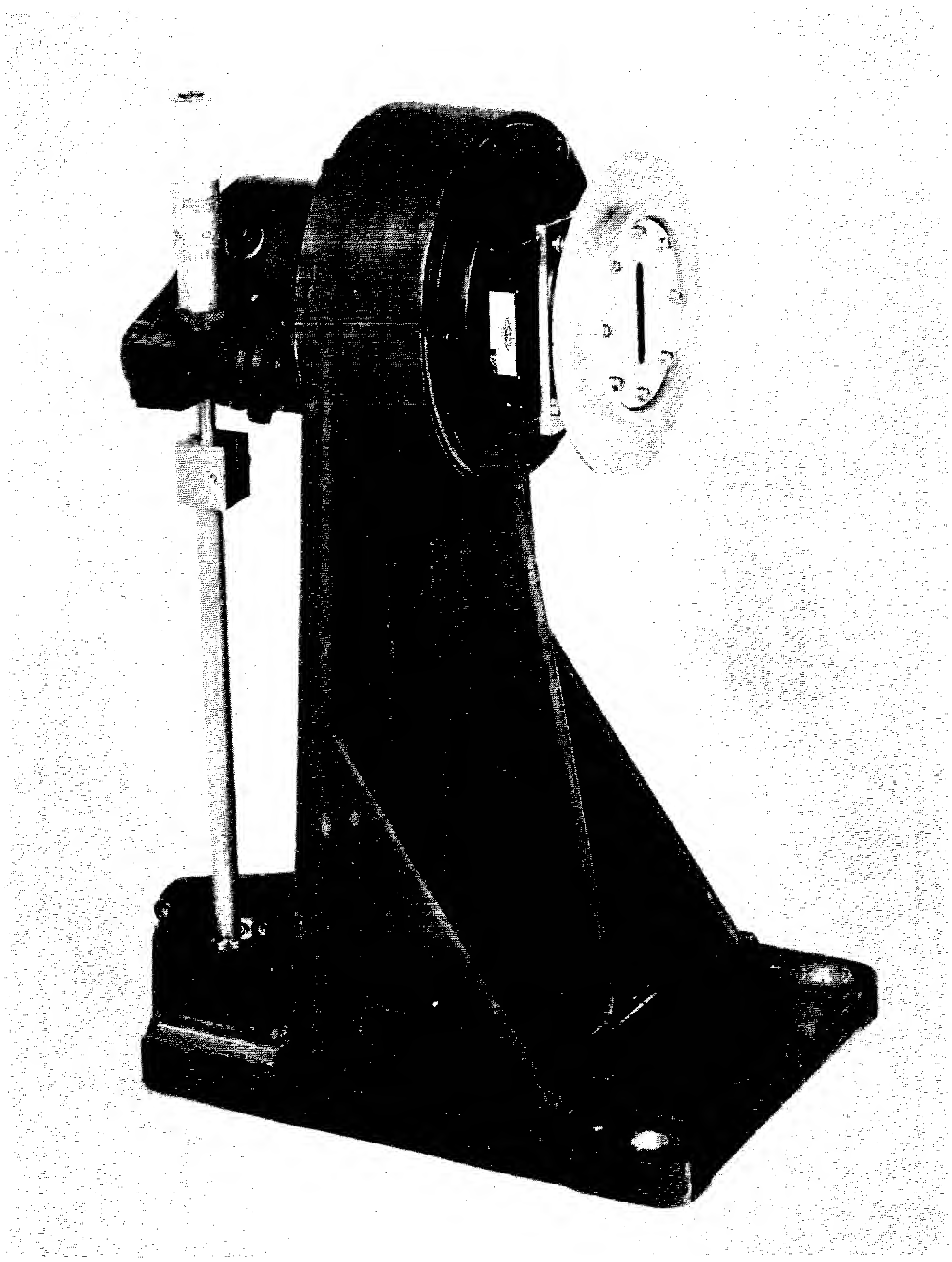
The lenses, mirrors, and platens were fabricated to exacting tolerances at Itek and certain selected optical companies. The lenses and platens were anti-reflection coated and mounted in precision cells. With the exception of the early cylinder lenses the optics have given no difficulty due to inadequate fabrication.

The entrance slit is a precision slit one inch long which can be closed down to a one micron width. The mount, shown in Figure 11, is designed so that the slit can be rotated around the optical axis to an accuracy of one minute of arc. The slit is protected from most of the intense radiant energy (estimated to be about 100 watts) focused on it by a double pre-slit built as a heat sink.

The folding mirrors are optically polished to a 1/8 wavelength specification. They are aluminized and overcoated on their front surface. The mounts, shown in Figure 12, hold the mirrors very rigid yet provide precise adjustments along the normal to the mirror and around two axies.

The collimator lens is a three element air spaced achromat, shown in Figure 13. It is diffraction limited in the tangential direction over a field angle of $\pm 3/4^{\circ}$, thus introducing almost no degradations in the collimation of the slit. The mount for the lens is shown in Figure 14. The lens can be moved one inch along the optical axis. Alignment adjustments can be made transverse to the optical axis and rotational alignment around the two axies perpendicular to the optical axis. Each of the motions are independent, can be set to .001 inch or 1' arc, and can be measured. The adjustments are designed to hold without jam nuts or other locking devices, experience has proven out the value of this feature.

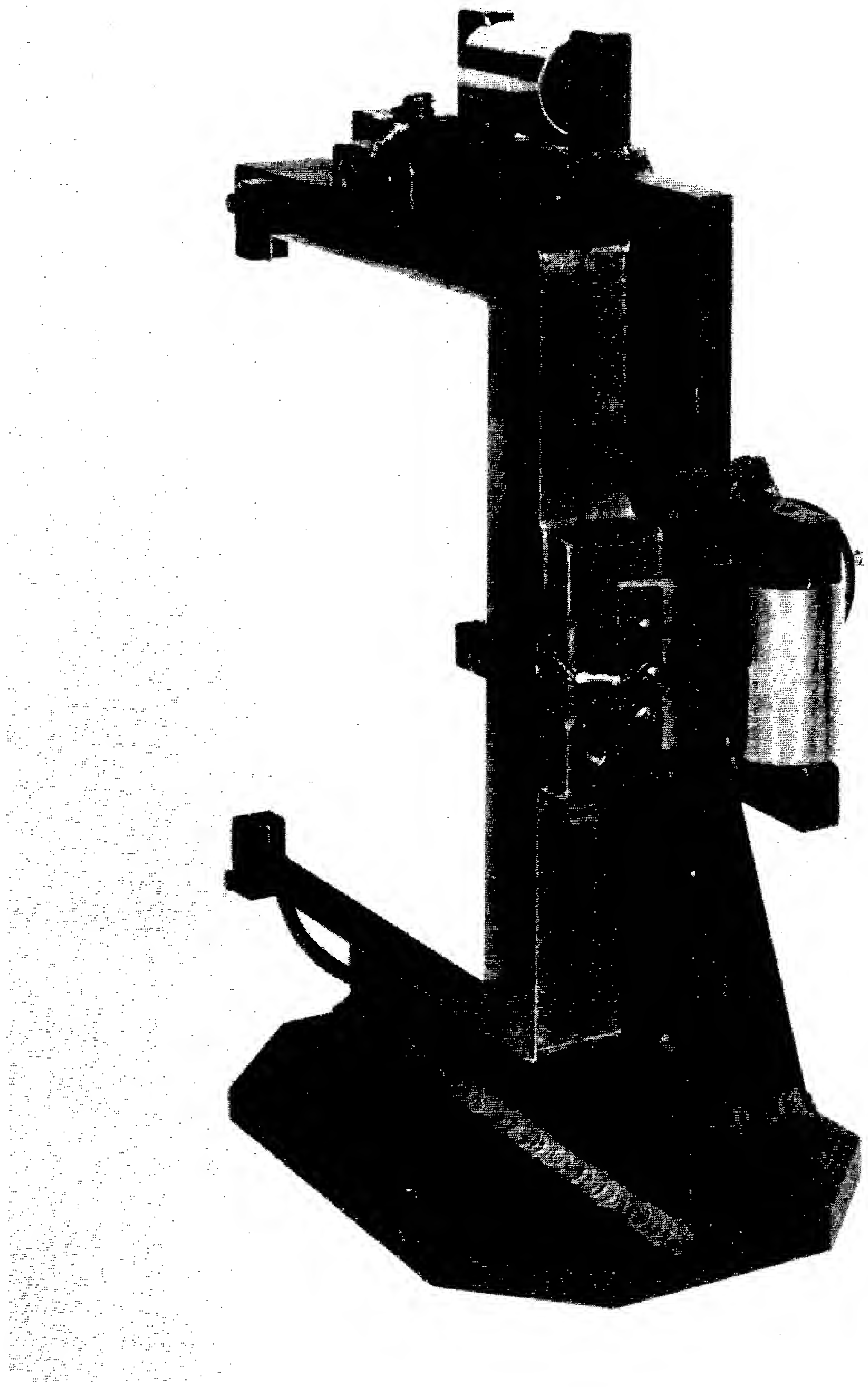
The field lens has a very simple task in the range direction as its name implies. However, in azimuth this lens reimages the azimuth image,



INPUT SLIT ASSEMBLY

The actual slit is behind the pre-slit

Figure 11



MIRROR IN MOUNT
Figure 12

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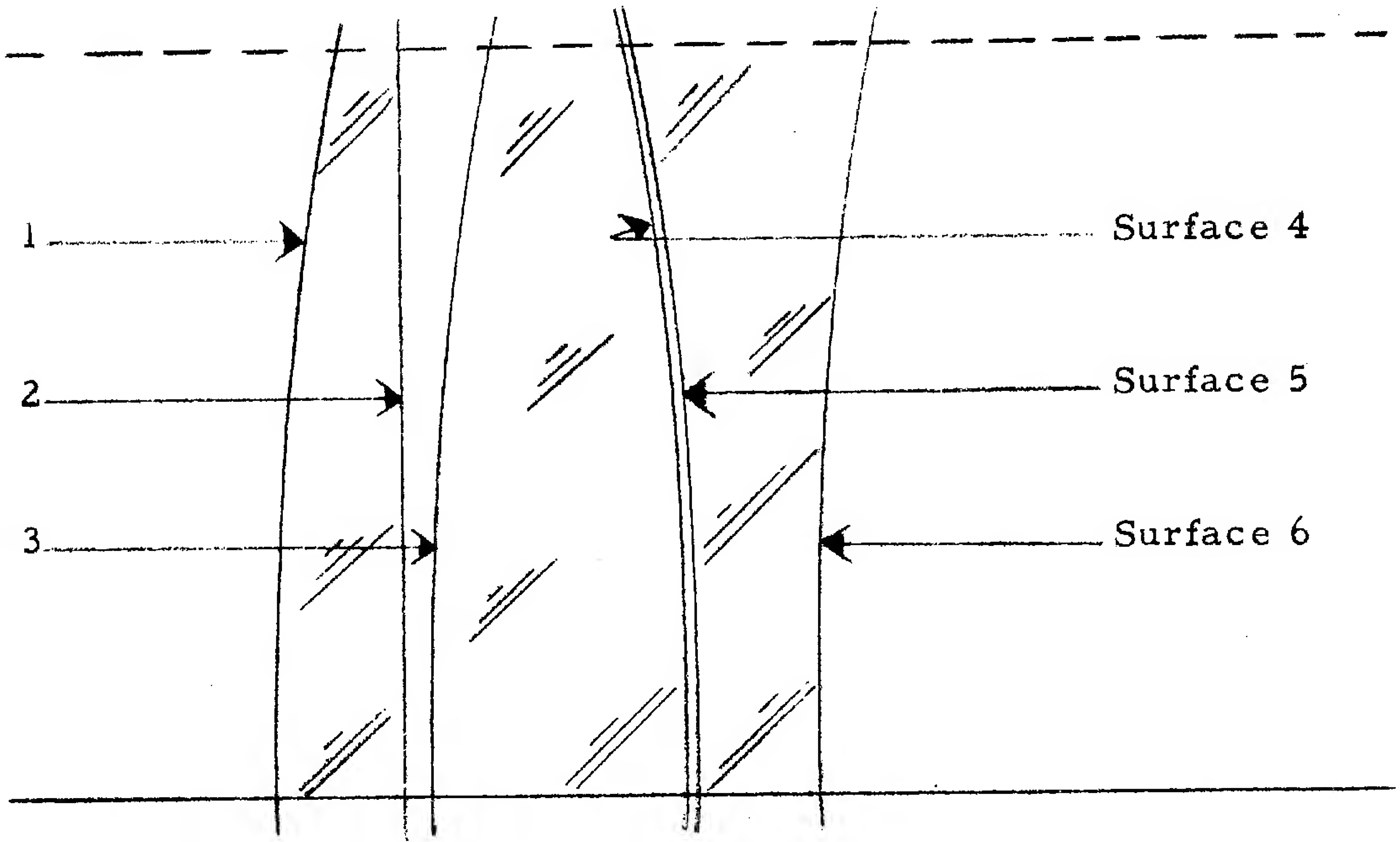
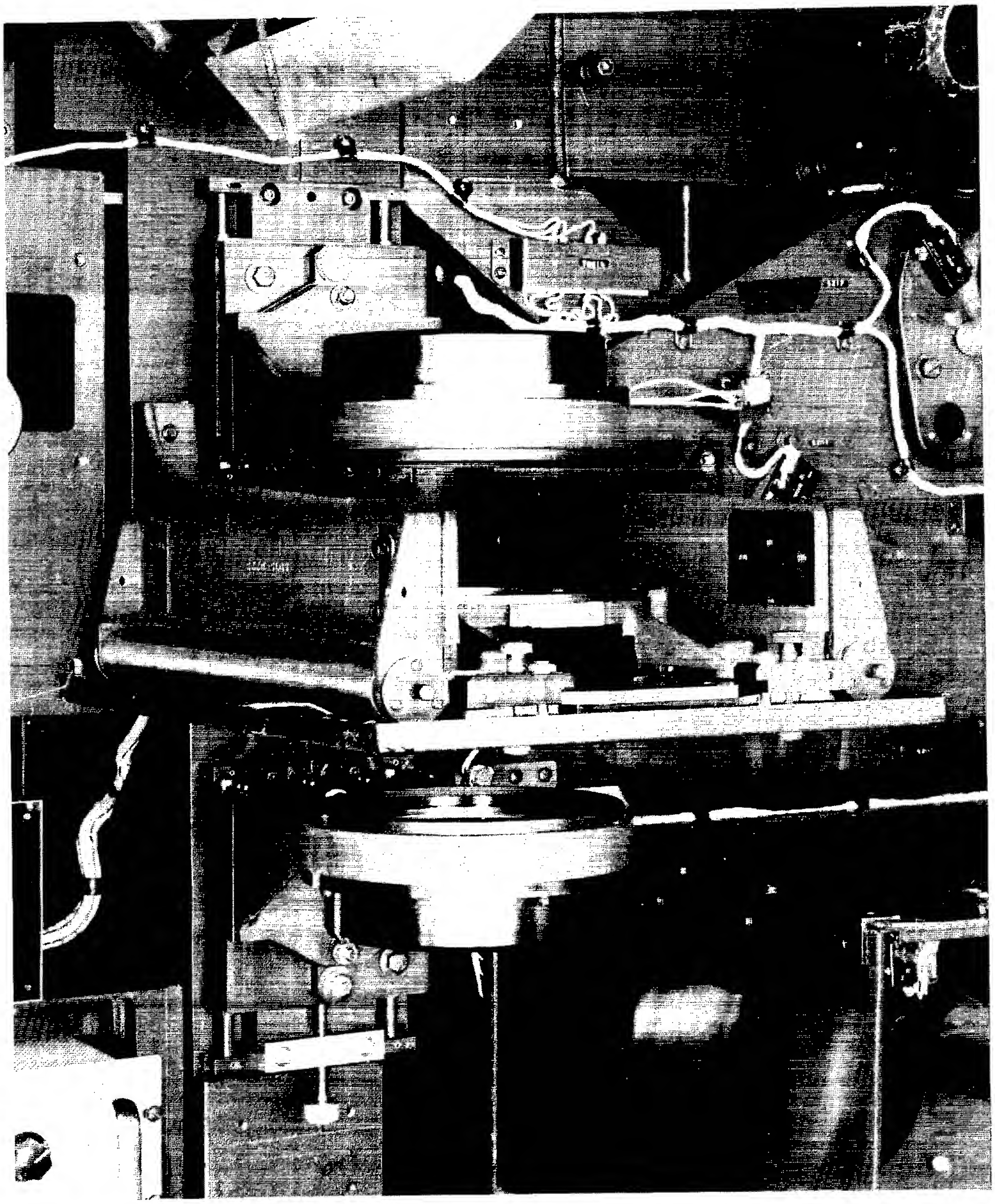


COLLIMATOR LENS SCHEMATIC

Figure 13

Focal Length 24.002

Element #	Glass Type	N_D	Surface Radius	Thick	Air Space
1	SK-16	1.6204	#1 - 18.6150 #2 - Plano	.4973	
					.0995
2	SK-16	1.6204	#3 - 17.5840 #4 - -20.1410	1.000	
					.0154
3	SF-2	1.6476	#5 - -19.6309 #6 - 24.4439	.4973	



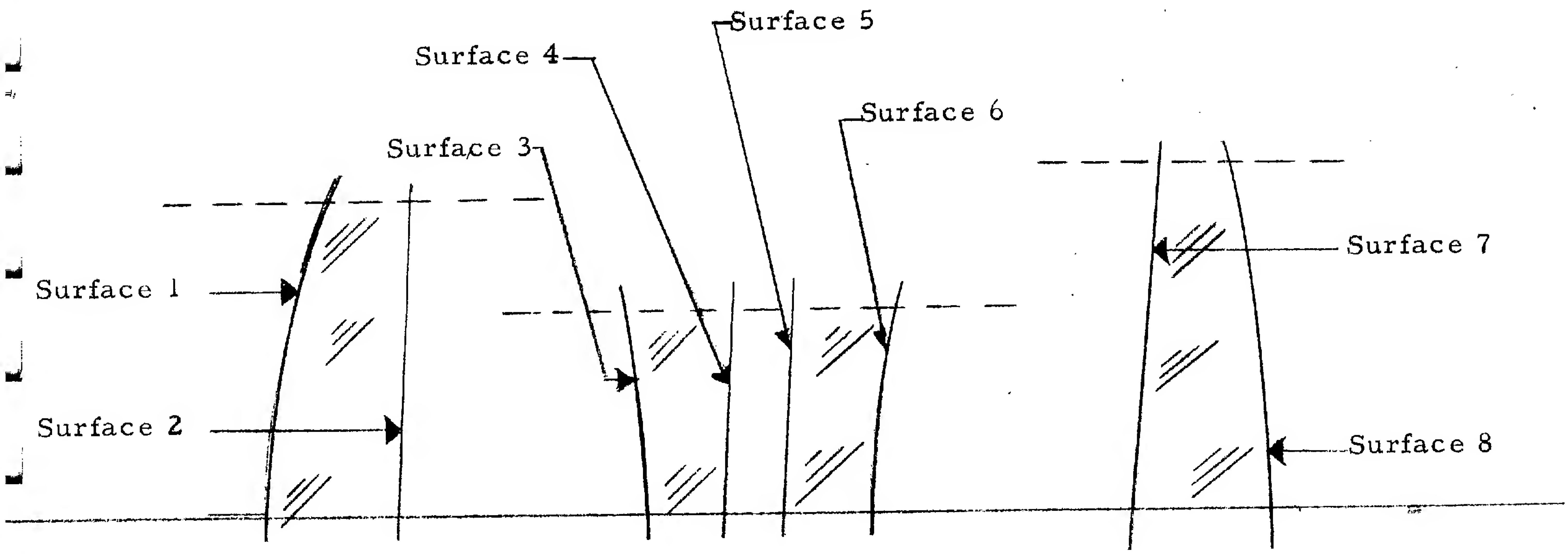
INPUT PLATEN AREA

The upper mirror (covered) is at the top, the collimator lens is below, the input platen (liquid tray) is just beneath the rollers. The field lens is below the platen. (The platen mount and tray design has been modified since this photo was taken.)

Figure 14

so its requirements are similar to those of the collimator. The field lens must perform over a field with a finite width of about $\pm 1/6^{o}$. The collimator design was found adequate for this purpose, so the same design was used. The mount is nearly identical to that used for the collimator as can be seen in Figure 14.

The relay lens is essentially a 2:1 enlarger lens shown in Figures 15 and 16. It works over a modest field angle of 5^{o}, and consequently a triplet design with a split negative element could be designed for adequate performance. The lens has a very flat field and is nearly diffraction limited in range as used in the processor. The relay lens should have very little effect on the azimuth image because the image is located near the principal plane of the lens. However, it has been discovered that the lens has considerable spherical abberation for conjugate points located near the lens. This does not cause an image blur because of the small section of the lens used by any one image point. However, it does introduce an astigmatic effect into any given image point. Since the object (ie primary azimuth image) is astigmatic, the astigmatism does not cause image blur but does shift the image along the axis. This has the effect of curving the field for best azimuth resolution, in the present case causing an inward displacement of about 0.7 inch at the ends of the field. A program is currently in progress to modify the lens so that it will have adequate abberation control for both the range and azimuth images.

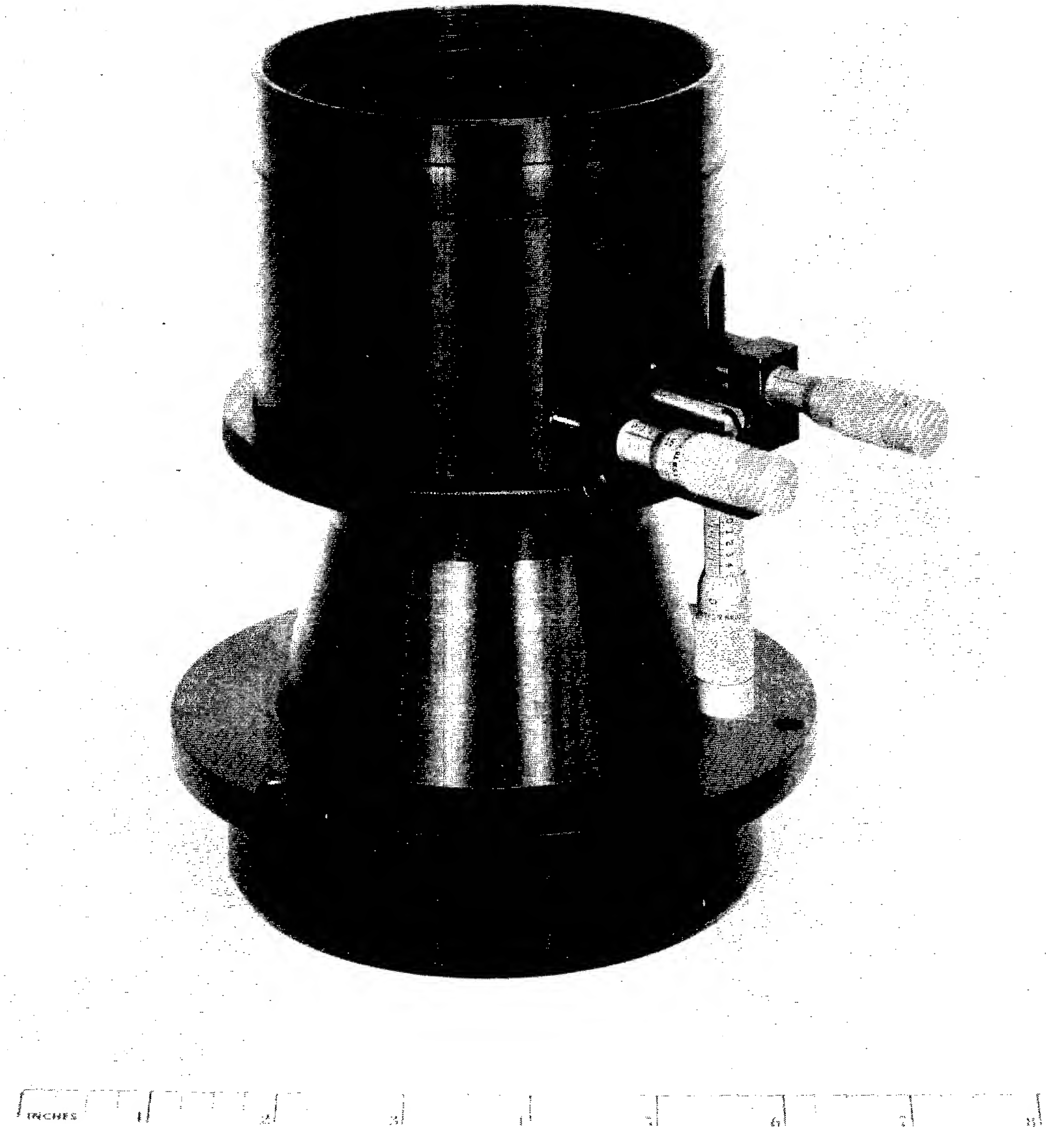


RELAY LENS SCHEMATIC

Figure 15

Focal Length 16.832

Element #	Glass Type	N_D	Surface Radius	Thick	Air Space
1	SK-16	1.6204	#1 - 4.3586 #2 - 66.6183	.7116	2.3844
2	SF-2	1.6476	#3 - -5.0963 #4 - 57.6858	.4448	.2847
3	SF-2	1.6476	#5 - 15.5982 #6 - 4.2585	.4448	2.3836
4	SK-16	1.6204	#7 - 14.6908 #8 - -7.7447	.7116	



RELAY LENS

Controls are for zero order stop

Figure 16

The zero order stop is mounted in the relay lens between the first and second elements as shown in Figure 17. This device has two slit jaws which are positioned in the azimuth direction (ie across the spatial frequency plane) with micrometers. The entire assembly can be moved along the optical axis for focusing on the frequency plane independent of the focusing of the relay lens. The slit jaws are sloped and coated with a black mirror surface to absorb most of the zero order light and reflect the remainder into a light trap. This procedure is necessary because the zero order contains about 300 times more light than the diffracted image. A neutral density filter to give a shaped transmission in the frequency plane can be mounted on the zero order stop.

The cylinder lenses are designed as achromats as shown in Figure 18. The design had to be completed without the aid of skew rays and the cylinders actually perform about as well as predicted. However, two effects on the overall system which were not predicted did arise and are discussed below. The fabrication of the lenses was not straightforward. The specifications were not beyond the state-of-the art, but the sizes, radii, and surface tolerances did present a combination which was unique. The first lenses (designed for the 24" focal length patterns) were unsatisfactory. The second set (for 150") was ordered from two of the leading manufacturers in the country*, and each of them had to make engineering

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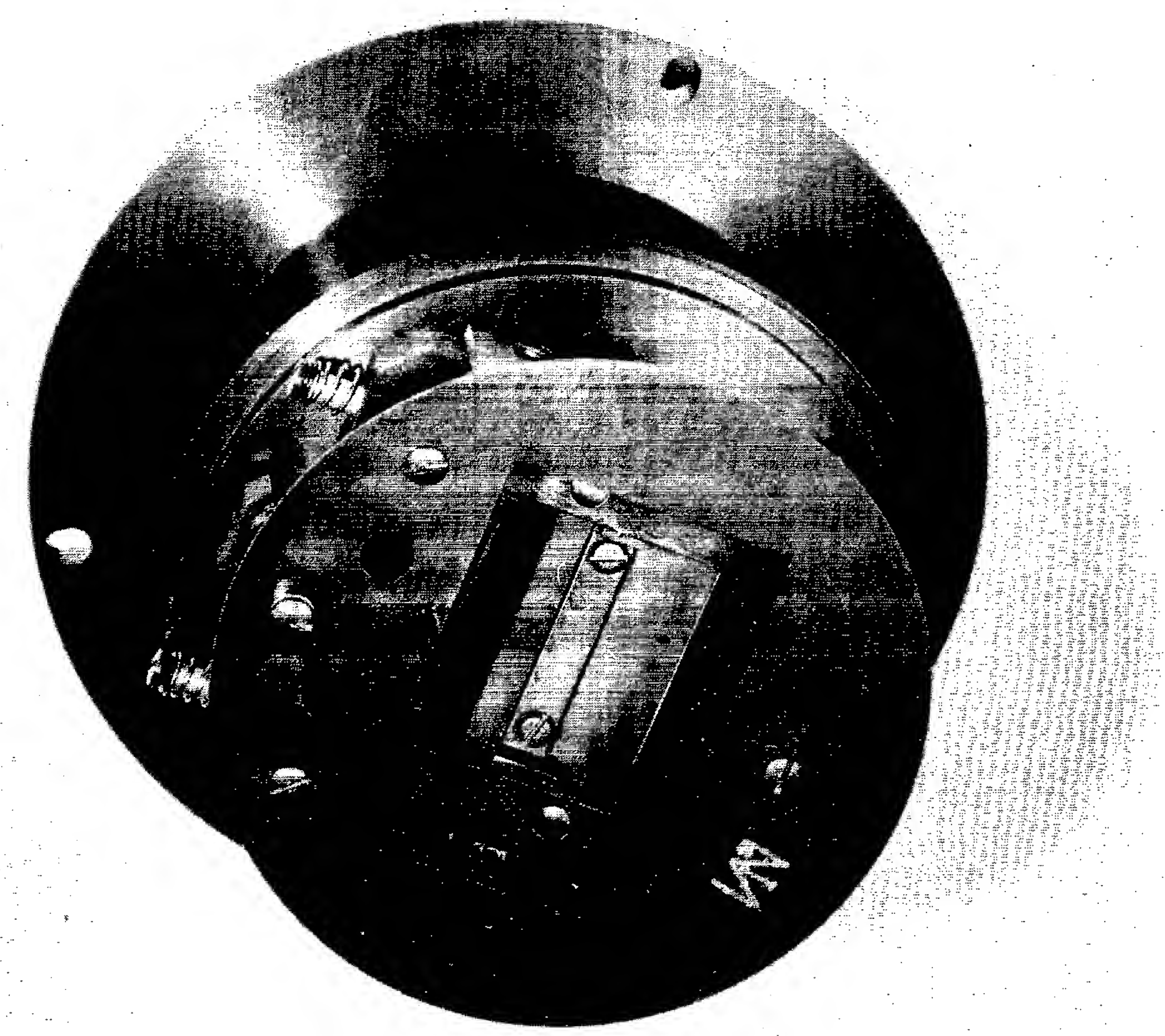
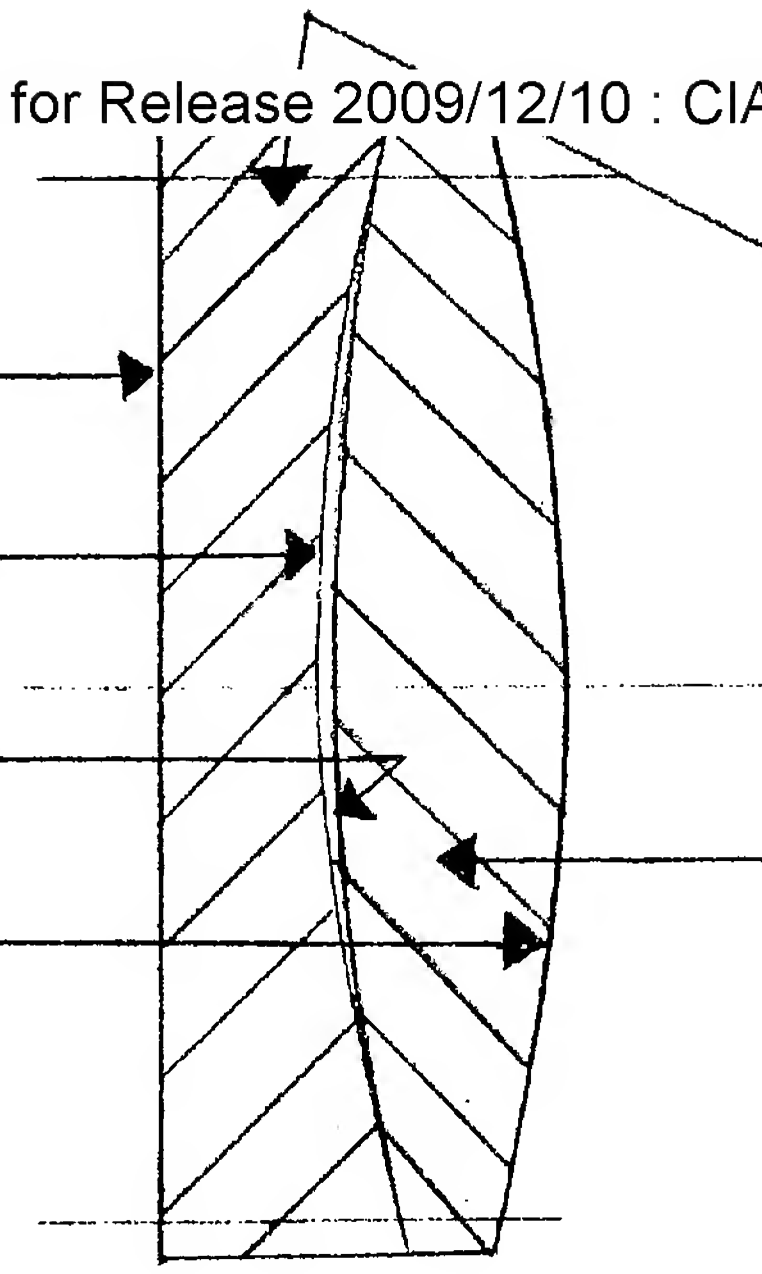
* Perkin-Elmer and Diffraction Limited. Itek did not have a cylinder lens capability.



ZERO ORDER STOP

The assembly is mounted on the lower portion of the relay lens cell

Figure 17



CYLINDER LENS SCHEMATIC

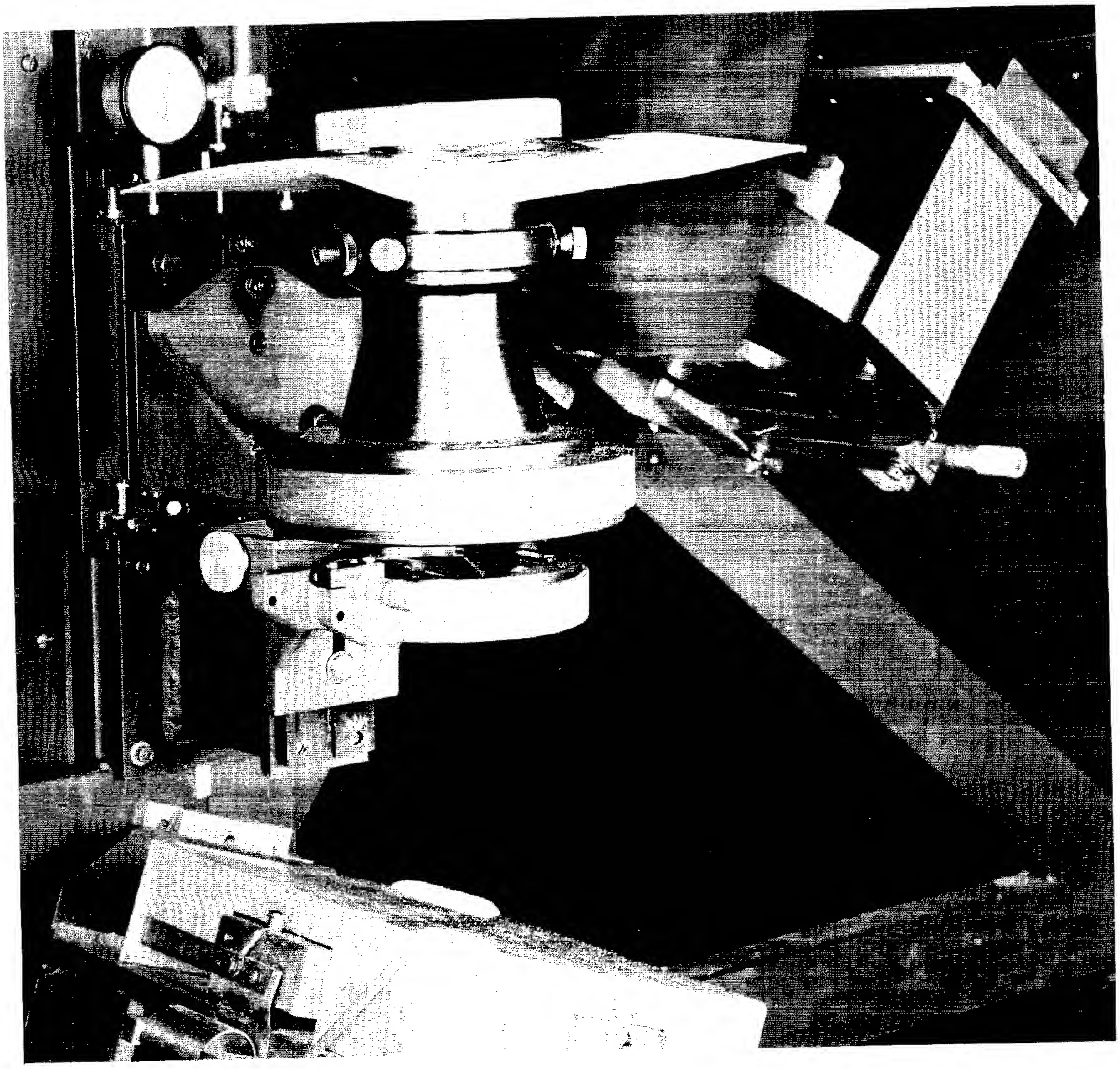
Figure 18

Element #	Glass Type	N_D	v	Surface Radius	Thick	Air Space
FIXED (focal length 11.292)						
1	SF-2	1.64769	33.9	#1 - +80.000 #2 - + 5.205	.400	.0373
2	SK-16	1.62041	60.3	#3 - + 6.061 #4 - - 6.124	.600	
NEAR (focal length 15.311)						
1	SK-16	1.62041	60.3	#1 - +6.667 #2 - -6.667	.600	Contact
2	SF-2	1.64769	33.9	#3 - -6.667 #4 - +25.696	.400	
FAR (focal length 20.557)						
1	SK-16	1.62041	60.3	#1 - +7.692 #2 - -7.692	.600	Contact
2	SF-2	1.64769	33.9	#3 - -7.692 #4 - +21.568	.400	

improvements to their equipment and procedures. However, they did produce the lenses to specification and the lenses performed as predicted.

The two troublesome cylinder lens "abberations" are the most serious of a large number of complex abberations which can occur with cylinder lenses. The first effect is that a bundle of rays traversing a cylinder lens at an angle to its axis is focused short of the paraxial rays by the factor of $\cos^2\theta$. This effect can be visualized by considering that the cylinder lens has different radii in different sections. The effect causes a curvature of the output plane (about 0.3 inch displacement at the ends of the field). The second effect also occurs at slant angles. It is caused by a parallel plate displacement and smears the image in range. The effect is small, on the order of .0004" maximum smear, but it becomes large rapidly if the lens is not accurately centered.

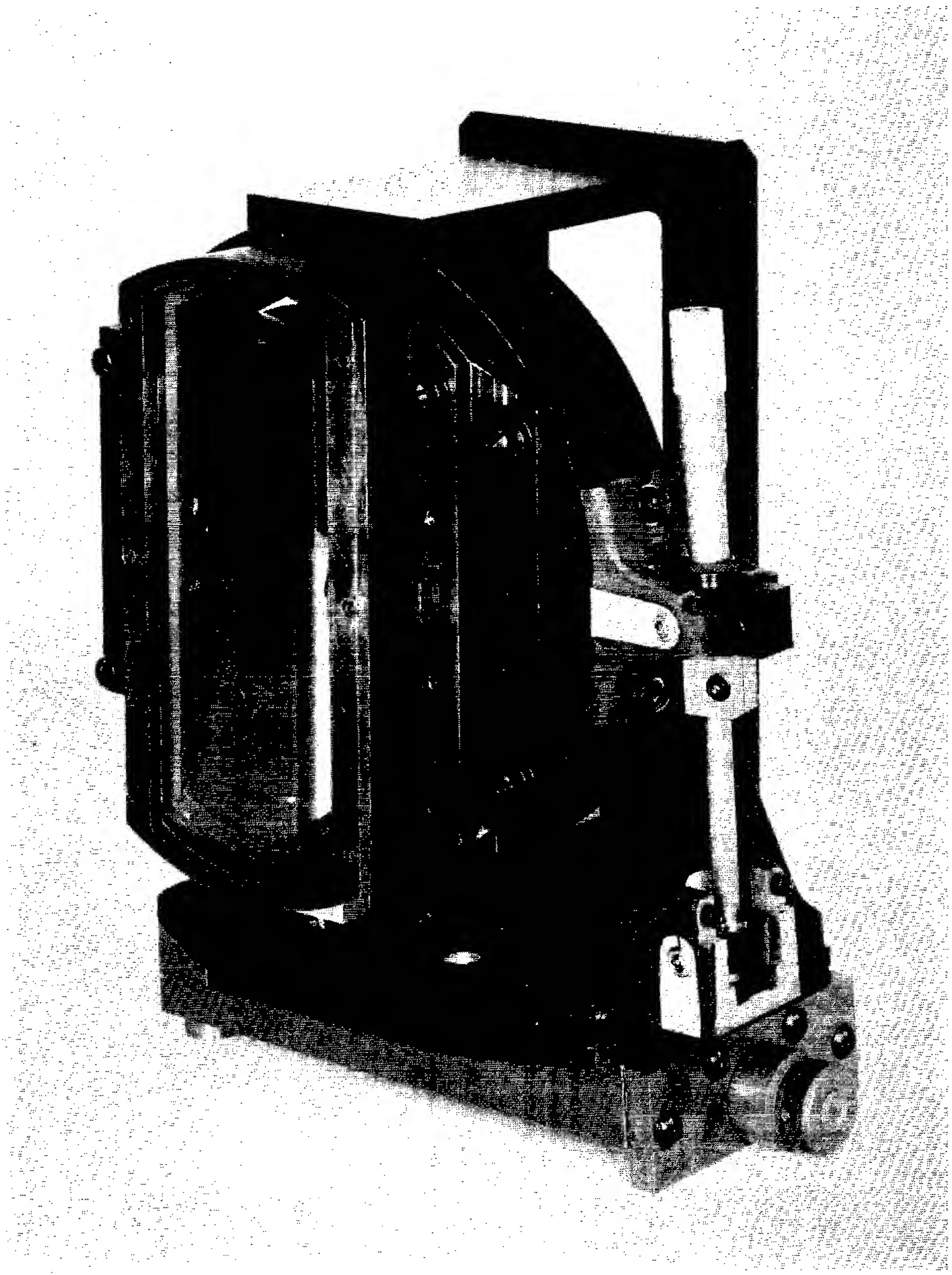
The cylinder lens near the relay lens has a mount designed to fit in the cramped space. It has a one inch focusing adjustment, a precision rotation about the optical axis, and simplified alignment provisions as shown in Figure 19. The larger cylinder lenses fit on a rotation drum mount shown in Figure 20 with precision translation across the axis as well as along the axis, and a precision rotation adjustment. The mount holds either of two cylinder lenses, one on each side of the drum, to accomodate either 150" patterns (near range) or 200" patterns (far range).



FIXED CYLINDER LENS IN MOUNT

The relay lens and mount is shown in the upper portion of the photo, the fixed cylinder is mounted below.

Figure 19



INTERCHANGEABLE CYLINDER LENS ON MOUNT

The far range cylinder is shown in place. The near range cylinder slides onto the other side of this mount. The slides which hold the lens have been modified since this photo was taken.

Figure 20

The wedge interference filter has a narrow transmission which shifts in peak wavelength at different points along the filter. The filter is shown in Figure 21 and a typical spectral transmission of one spot on the filter is given in Figure 22. Two filters are used, one for each range swath. The specifications for the filters are within the state-of-the art, but the combination of requirements are unique and the vendor* has had to solve many engineering problems in fabricating the filters. The discontinuity in the center is due to the limitation of his equipment requiring that the coated elements of the filter be made in two sections. The filter is mounted in a slide just in front of the film.

C. Accessory Optical Systems

The data block exposed on the side of the input film is transfered to the output film by a data optics link. This is essentially a 1:1 projection lens with suitable mirrors to relay the image from either of two positions of the data film down onto the edge of the map film. The illumination is by instantaneous flash to avoid image motion smear. The flash is triggered by a photocell circuit which senses the presence of a data block.

The output image can be viewed on a television monitor. A mirror in front of the exit slit intercepts the image (or a portion of the image) and reflects it down to a low light level television camera. The primary image is formed at an intermediate plane (which contains an interference

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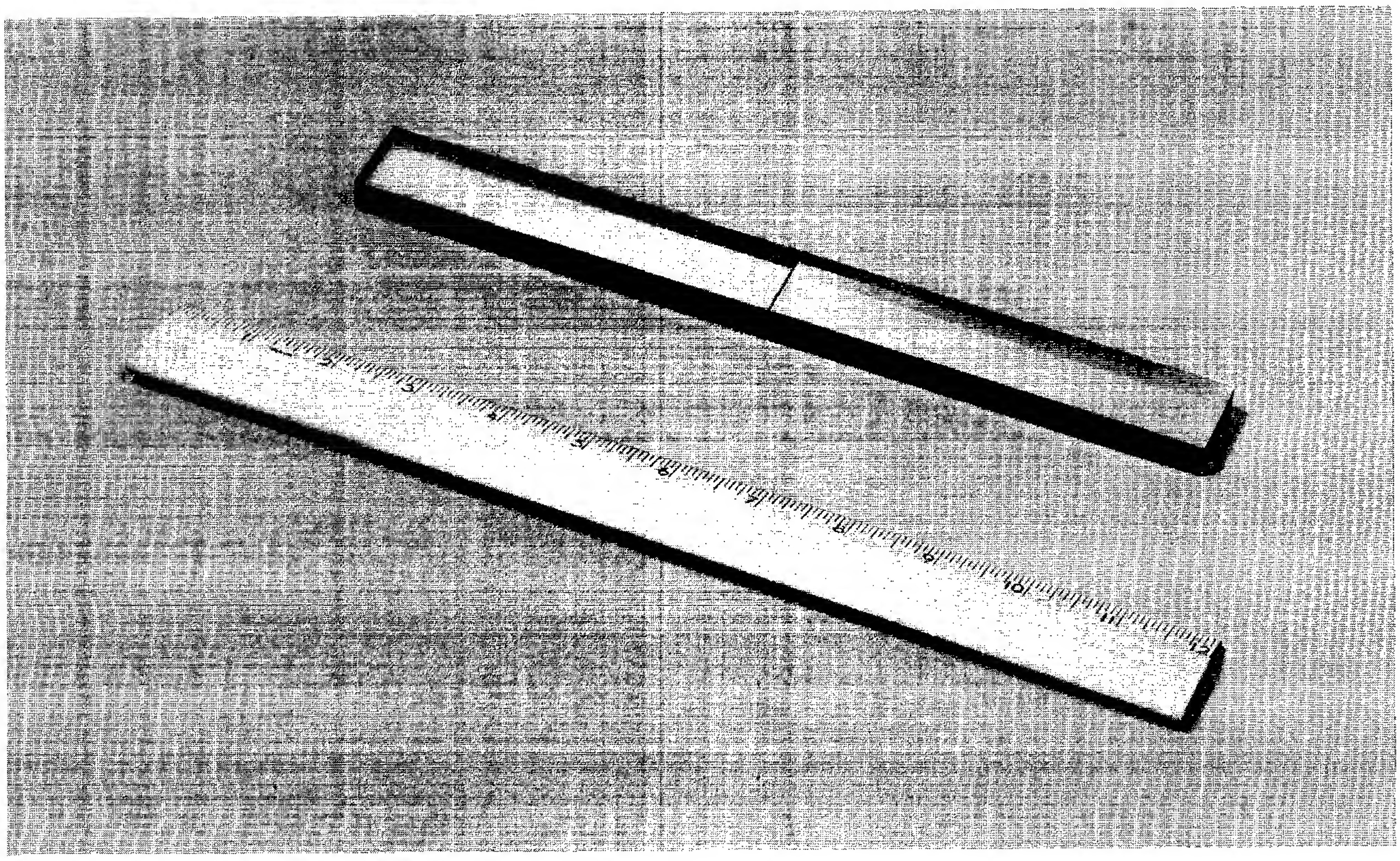
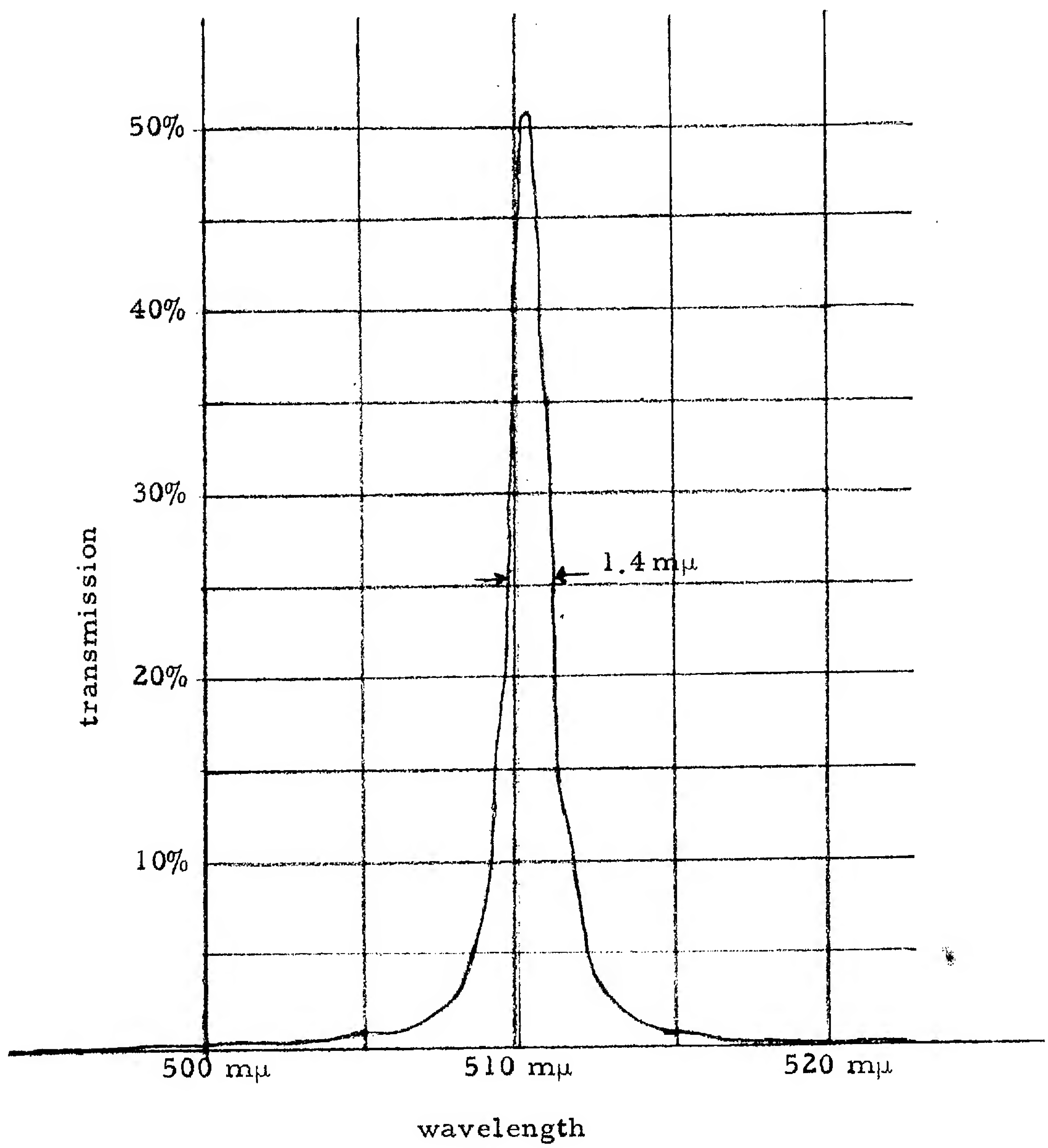
* Spectrolab Inc., the only company to respont to our original request.



INTERFERENCE FILTER

Figure 21



SPECTRAL TRANSMISSION OF INTERFERENCE FILTER

A very small area of the filter is used in making this measurement. Different areas along the filter give different peak wavelengths.

Figure 22

filter and field lens) and is relayed by one of two enlarger lenses onto the camera tube. This provides for a selection of magnification. The system is designed so that it can observe the edges of the image strip while the center of the image passes through to the film. The television camera is an Admiral Transistorized image orthicon model 1480, with a Z5294 tube. The monitor is a standard studio monitor.

A camera station can be inserted in place of the TV mirror assembly. In this unit, the central 5 inches of the path is reflected toward the front of the processor onto a standard 4 x 5 camera back. An interference filter can be inserted in front of the film plane. The image can be viewed on a glass screen or recorded on film.

A microscope was originally installed to view the image. The microscope had a special body and folding prism to allow for observation all across the field. The microscope viewed an image which was reflected by a special mirror surfaced jaw on the output slit. This unit has such a small field of view that it was seldom possible to recognize any images. This unit was removed when the TV system was installed, but is available to be remounted at any time that increased resolution or new requirements make that desirable.

The light distribution in the spatial frequency plane can be viewed by mounting the 4 x 5 camera unit above the relay lens. A special baseplate permanantly fastened to the frame permits the mounting in less than one minute.

D. Film Drive

The small optical field angle in the azimuth direction requires that the unit operate as a continuously moving enlarger. This demands that the motion of the input film be matched by a similar motion of the output film. This is a very difficult task and is not attempted by any known commercial equipment nor by any known special purpose enlargers or rectifiers. There has been a rectifier and coherent radar processor built which use moving film, but the devices we are aware of use an output slit which is approximately equal to the resolution limit so that any relative motions introduce only distortions and do not reduce image resolution. The difficulty of the problem was recognized at the start of the project and very much design and development has been expended on the film drives. All of the assemblies are very precise (many dimensions are held to .0002" tolerances) and run on the best bearings available. The drive apparently* has met some of the requirements, but it is marginal or unsatisfactory in some respects.

The drive system will be discussed under the headings of the three chief requirements, which can be briefly summarized as follows:

1. Uniform speed: accurate to ± 5% over a speed range of .002 to 2 inches per second for the input data film (original requirement: 4 selectable speeds of 1/4, 1/2, 1, and 2 inches per second)

---

* Direct tests of the unit are beyond available measurement techniques. Indirect tests depend on many factors and are not considered conclusive.

2. Drive Ratio: Motion of output film to match the motion of the image to an accuracy of .0005'' or better (.0002'' was the initial goal). This implies that the drive rollers move in exact synchronism except for a speed ratio factor. The speed ratio must be variable over a range of ±1% or more. The drive ratio factor M_o must be set equal to the optical magnification M_o to within an accuracy of 0.2% in order not to exceed the allowable image blur. The drive ratio must be such so as to avoid any periodic, random or long term variations in excess of this amount. In addition, there should be no independent motions of the output film in excess of .0002''.
3. Tracking: The input film should track properly to an accuracy of ± .005'' lateral position and less than .0002'' lateral position change while advancing one inch. The error in angle should be less than 1 minute of arc.

Uniform Speed: The first requirement is based on the need to avoid banding of the output image due to exposure variation. It was originally satisfied by a synchronous motor with switchable field coils to select the four speeds.

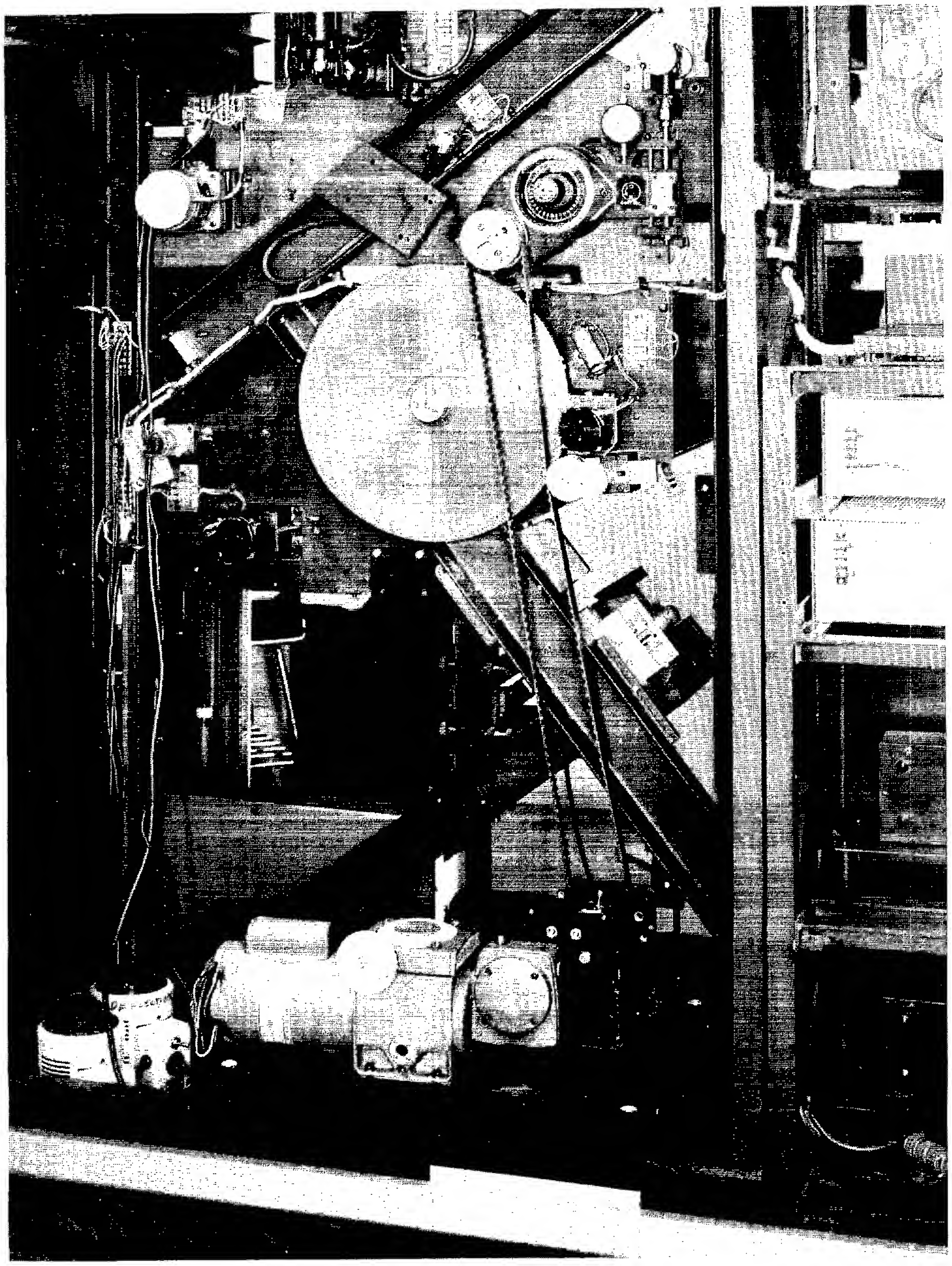
Experience indicated the need for a wide range of speeds to accomodate all test and running conditions. The original motor was replaced by a variable speed drive and gear box to achieve a 1000:1 speed variation. The speed uniformity has not been checked (the slow speeds preclude the use of standard instruments) but no banding has been noticed.

The mechanism which maintains the relationship of the wheels must be very precise and rigid. The new unit is shown in Figure 23, it has functioned very well.

Drive Ratio: The maintenance of a constant but selectable drive ratio is the most difficult problem, and its achievement has been the primary goal in the film drive design. A number of techniques were studied, including digital servo devices with electronic ratio control, hard surface speed changing devices (ie cone wheels), gear systems with differentials for small variations, and soft wheel ratio control features.. The speeds involved are very slow, the torques are small and vary somewhat.

The technique chosen was the soft wheel drive. This device was tested in detail on the fixture shown in Figure 24. The action is shown in the sequence in Figure 25. The white ink dots on the rubber tire can be seen to advance more rapidly than the radius line in pictures 3, 4, and 5. The rim of the rubber is going at the rim speed of the metal wheel, so the lower wheel is traveling slower than would be expected. This effect is independent of speed, direction, or which wheel is driven. The magnitude of the effect depends upon how deeply the metal wheel is pressed into the tire. In 1963 a new drive was installed and a survey of available techniques again led to the selection of the soft wheel.

Previous experience with the precision drive system in the recorder (a separate project at Itek) indicated that erratic effects from the film reel assembly could not be eliminated. For this reason, a loose loop was designed into the film path between the spools and the main drive so that no forces could



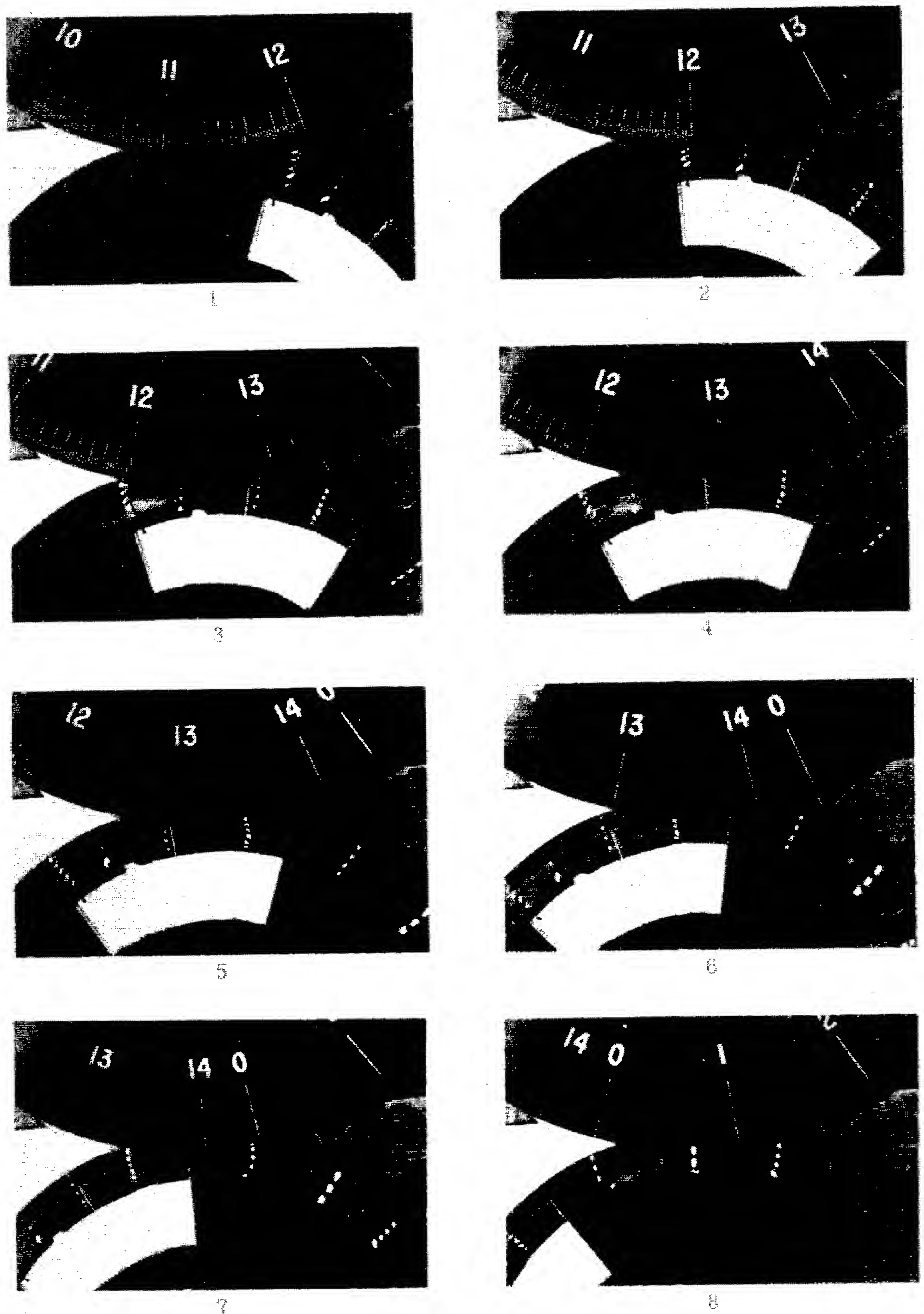
FILM DRIVE

The speed controller and gear box are mounted on a vibration-isolation plate at the bottom. The drive wheel (behind the pulley) drives the large metal wheel and small rubber tire wheel. The speed ratio is varied by the controls at the upper right.

Figure 23

RUBBER WHEEL TEST FIXTURE

Figure 24



ACTION OF RUBBER WHEEL DRIVE

Figure 25

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be transmitted. This is accomplished by a roller assembly which pulls the film from the spool and lets it hang in a loop before it enters the main drive section. The size of the loop is maintained by one or two delicate micro-switches which control the roller assembly. There are four such units, one for each film spool. These loop control units have performed their basic task quite well; but they have caused considerable trouble due to tracking problems, as will be discussed below.

The drive ratio can be set and maintained to an accuracy of 0.07% or better over long periods. The short term variations have not been measured since there is no known equipment for performing this test. There has been no indication that short term variations do exist. The drive ratio can be varied over a range of about $\pm$ 1% with one wheel. Additional rubber wheels can be used to extend the ratio variation (3 wheels are presently available, unfortunately, their ranges do not overlap).

The drive system has the disadvantage that it links the input and output by a precise mechanical link. This is often incompatible with the optical link joining the same two parts. This has been one of the most serious drawbacks of the mechanical drive system since it prevents mobility of the output platen for focusing, removing (for observation or special tests), or relocating for design changes. Nevertheless, the most obvious and difficult specifications have been met.

Tracking: The much more subtle problem of tracking also received considerable effort, but without complete success. The initial design used fixed and spring loaded edge guides to attempt to keep the film against a reference edge and thus maintain the same position control as existed in the recorder. This technique caused chattering of the film in the recorder and was abandoned there. The film often tracked under or over the guides in the processor, so the technique was abandoned here also. At the present time, the guides are rigid and are set wider than the widest tolerance on the film. This allows the film to wander and change angle, but the effects are small enough during a run that it does not cause any obvious degradation (partly because the optical system and data film are not "ideal"). The most serious difficulties have arisen from non-dependable operation due to gross tracking error (especially in the loop control rollers) and the fact that the rotation angle of the film is different when the film is stopped, thus frustrating most alignment techniques.

The tracking problems seem to arise from the following causes:

a. A firm grip on the film between a drive roller and pressure roller (necessary for precision and dependable drive) precludes any control of the film by the edge guides. Techniques using narrow pressure wheels, loose or floating rollers, and pressure belts have been partially successful.

b. The loose loops eliminate tracking forces so the tracking must be reestablished at every drive station. The most serious problems have arisen at the loop control stations, especially those just before the take-up reels.

c. The input film must track correctly while flat between the input platens. When flat, the film tends to curl and not respond to edge guides. Attempts to guide at the platen have been only partly successful. Conversly, the tracking at the output platen (a roller) has seldom been a problem.

d. The input film must be tracked in two positions to bring the front half or rear half past the platen. This greatly complicates the roller and edge guide assemblies. The initial design used 14 inch long rollers with groves where necessary for edge guides. The design is still used on the precision assemblies, but the pressure rollers and one loop control roller station has been redesigned and now moves the entire assembly for the two positions.

Experience has indicated that the precision mechanical tracking is very difficult, and the techniques which must be used tend to preclude dependable control over gross tracking errors. Present plane for drive improvement, or the drive in another processor, would be based on a servo system which optically senses the position of a line exposed onto the edge of the film in the recorder and moves the entire film drive platen assembly to maintain the data film alignment. This technique had been considered at the initial design but ruled out as being too complex to complete and perfect within the short schedule time.

V. PERFORMANCE

General

The processor will make map film 9 inches (10 nautical miles) wide at a rate of 12 feet (160 nautical miles) per hour.

The resolution on the map is dependent on the entire system, and is expected to be on the order of 20 to 35 feet for most targets. The image degradation contributed by the processor is usually expressed as the width of the image that would be obtained if ideal data film were available. In the range direction this would be 8 feet, in the azimuth direction it would be 20 to 28 feet over most of the map but deteriorate to an extreme of 50 feet at the edges of the map for single pass runs.* The azimuth resolution can be improved to 8 or 10 feet for any given target area if desired.

Processing Rate

The speed of processing film is on the order of 12 feet of map film per hour covering an area of 160 x 10 nautical miles. This speed depends on various adjustments in the processor as well as certain characteristics of the data film. However, it is unlikely that conditions during later tests or operation will change the film speed more than a factor of two either way. The recorder will hold 500 feet of film and thus obtain data from a 1500 x 20 mile area, this will require 16 hours of running time. The set-up time for a single run may vary from 2 minutes to one hour depending on operational and maintenance procedures.

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* The location of best and poorest resolution is at the discretion of the operator.

The time required to re-adjust the processor for optimum performance on any given target area can range from a few minutes to a full working day, depending on just what is desired. For example, an easily identified target on a short piece of data film could be photographed statically within 5 minutes. On the other hand a larger target which must be photographed with the film running and which contains important information could easily require many repeated runs in order to obtain the maximum amount of information about the target. The complexity of the optimumization process is due in part to the processor itself (primarily film tracking inaccuracy) and in part to the complexity of the overall system which can introduce many ambiguities, as is well known by anyone who had adjusted a correlator.

Range Resolution

The range resolution of the optical system has been measured by three techniques. These gave approximately similar results and indicate a resolution capability in range of .0012" half power spot size, or 8 feet at map scale. A diffraction limited system would give a spot size of .0009", indicating small loss due to abberations, film resolution, or image motion.

The earliest measurement was made visually with the aperture of the lens at 2.0 inches. This gave limiting resolution of 130 l/mm on axis and 45 l/mm off axis as referred to the data film. 1* A one inch aperture is currently in use, since the above figures indicate that the system is near

* The circled numbers identify the source reference in Table I at the end of this section.

the diffraction limit, we can estimate that the current value would be about 70 and 50 to 60 l/mm respectively, ie 35 to about 27 l/mm at the output plane. This would indicate a half power width of .0011" on axis and .0014" off axis.

A second test was performed by placing a square wave target with a frequency of 40 l/mm in the input platen and recording the resulting image on film.(2) The density of this image was measured on a microdensitometer to determine the contrast. The values for one good focal setting were 58% contrast on axis and 35% off axis. This would indicate half power widths of .0007" on axis and .0011" off axis.

The range resolution has also been measured by inserting a film with a set of very narrow (.0002") clear lines. These would form a set of geometrically ideal lines .0014" wide on the output. The image was recorded on Royal-X Recording film and the test was run with the films driving at normal speed. The measurement gave a line width of .0012" on axis.(3) The lines near the edge of the field were not measured but they appeared to be very little wider.

Azimuth Resolution

The azimuth resolution is not as clearly defined since more parameters affect the measurement, and the effective resolution will depend on how the processor is being used. One criteria is the average capability when the processor is adjusted to give the full 8 1/2 inch width map. However, the

unit can be readjusted to give better performance on axis or at any given range interval if desired. In addition, some further improvement can often be expected if images are examined and photographed while the film is stationary. Certain parameters of the input data and certain operational adjustments can also influence the azimuth resolution capability of the processor. These variations in capability arise because the input image "plane" is curved, the image spread is a function of the bandwidth passed by the correlator, some adjustments are comprised for processing speed, the film tracking is not perfect, the data is not perfect, and it is usually impossible to accurately determine the optimum adjustments.

The processor is normally intended.to process the entire 8 1/2 inch width while running at a nominal speed. The best data relating to this situation was taken statically (ie film drive not running) and gave an average line width of .0042", the narrowest width was .0029" and the widest was .007".(4) An overlapped target resolution test was run dynamically and half width computed from the results give width of approximately .005 average, .004 best and .006(5) for the poorest. In actual operation the entrance slit would be wider and the band pass would be smaller (the test used a band pass of about 575 cycles per inch) so that the azimuth resolution which can be expected will be on the order of .003" to .007" with an average of about .004". These values are verified by some of the maps made with the F101 flight test films.

A recent flight test (S87) flown past a bank of test reflectors gives an indication of the overall system performance at this time, see Figure 26. The reflectors spaced 20 feet apart (.004" on map film) were resolved when processed normally as well as when processed statically with laser light, Mercury green light (visual observation only) and white light with the wedge interference filter.

An alternative method of using the processor will give considerably better azimuth resolution over small selected areas. In this case the processor can be focussed specifically for the range of the target and the entrance slit can be adjusted smaller. In addition, if static pictures are adequate or if an hour or more can be devoted to adjustment and re-runs of the one area, the rotation adjustment can sometimes be improved, the band pass can be adjusted for optimum resolution, and finer grained films can be used. Under these conditions the correlator can be adjusted to give an azimuth spot size of .001" or less if the data film is of adequate quality.* The tests have been run with near-perfect ruled targets and widths of less than .0009" have been attained on axis. 6 A test with more monochromatic illumination (a laser) gave image widths of about .0005" on axis and off axis, 7 which is an indication of the inherent capability of the optical system.

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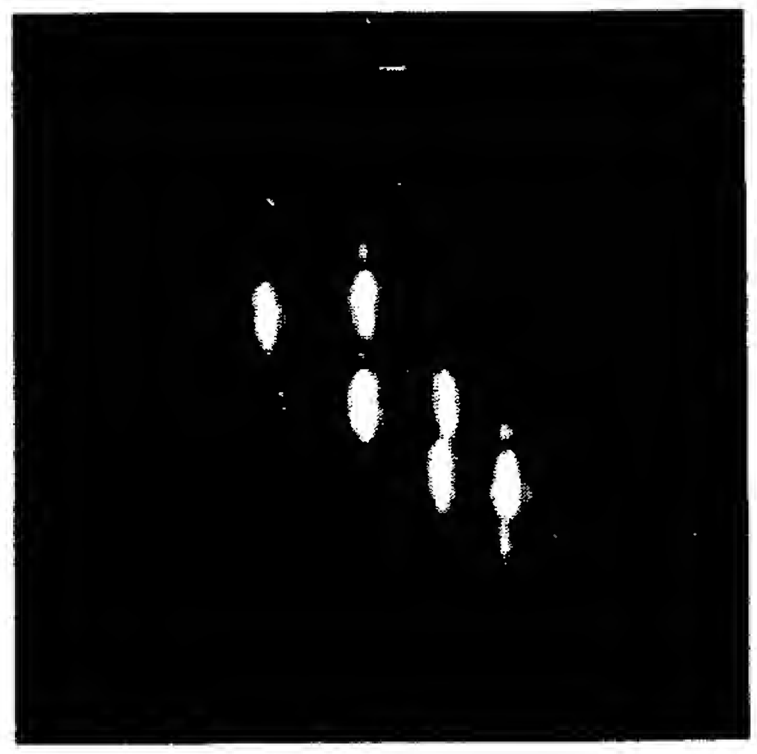
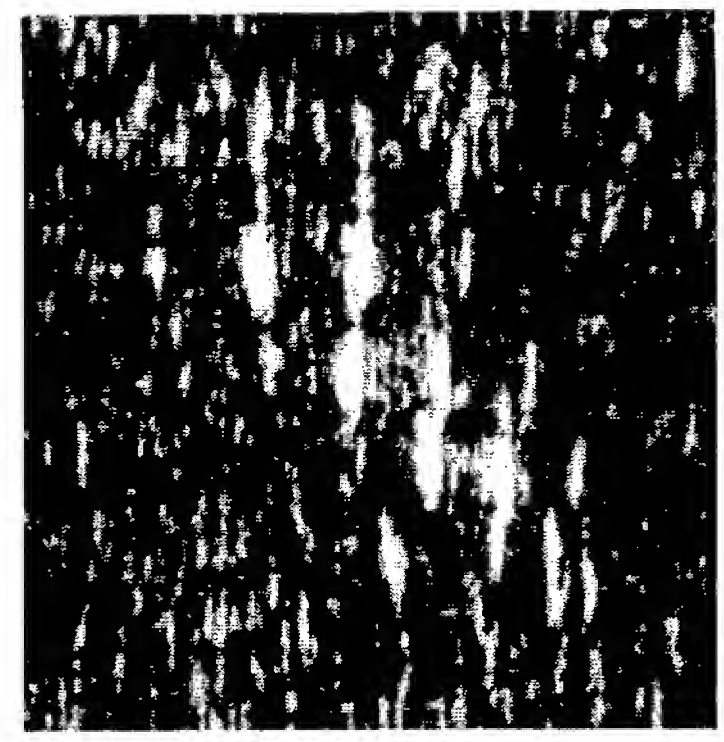
* If the data film does not have data good enough to achieve resolution close to this value, then adjustments which depend on the target details (ie focal length, target tilt angle, and target frequency content) can not be made precisely enough to insure that the correlator itself is working to a spot size of .001".

NORMAL RUN
S87 CN11

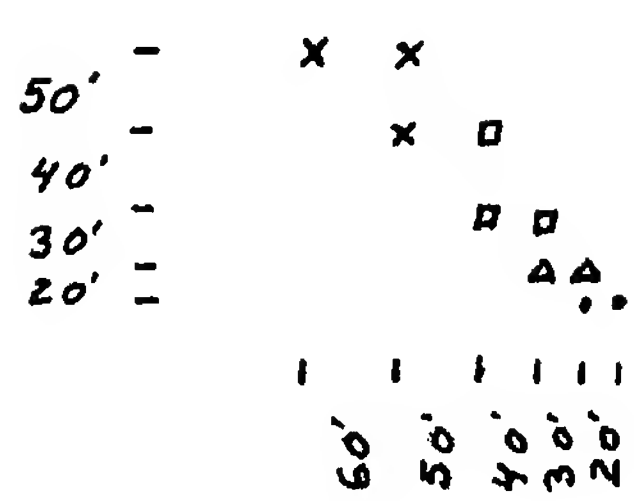


CARBON ARC
(Static)



LASER
(Static)

LAYOUT



× 3630 sq. ft.

□ 215 sq. ft.

△ 345 sq. ft.

• 35 sq. ft.

Photographs enlarged
20x from output image

TARGET AREA

CORNER REFLECTOR TESTS

Figure 26

TABLE I

Reference	Basic Itek Notebook References	Progress Report
1		Feb 1962
2	Notebook 934 P20	Feb, Aug, Sept 1963
3	Notebook 934 P52	
4	Notebook 934 P22	Aug 1963
5	Notebook 934 P51	
6	Notebook 934 P53	Feb 1964
7	Notebook 934 P54 Notebook 916 P17-20	Feb 1964 Jan 1964
8		Feb 1964

VI. CONTRACT ITEMS OTHER THAN THE PROCESSOR

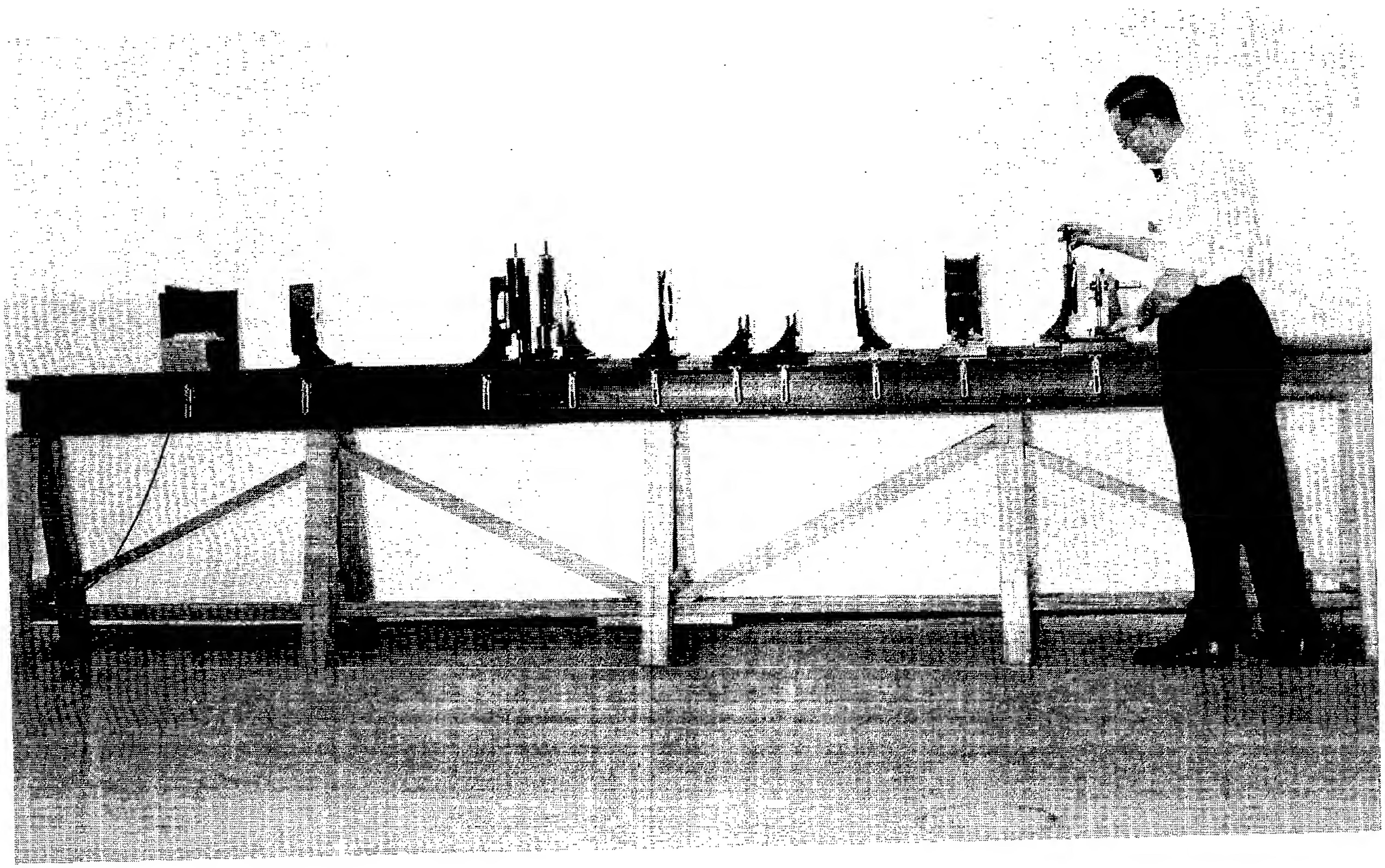
The contract has called for a number of items other than the processor itself. These items are listed here.

Monthly Reports - A short progress report has been submitted monthly. For a period of about one year the report also contained some technical results from the Test and Simulation program.

Operational Manual - An operational manual has been published in two parts, an unclassified section and a small classified addendum which contains optical alignment information. The manual supersedes a preliminary manual published in 1962 to serve as an aid to an experienced operator.

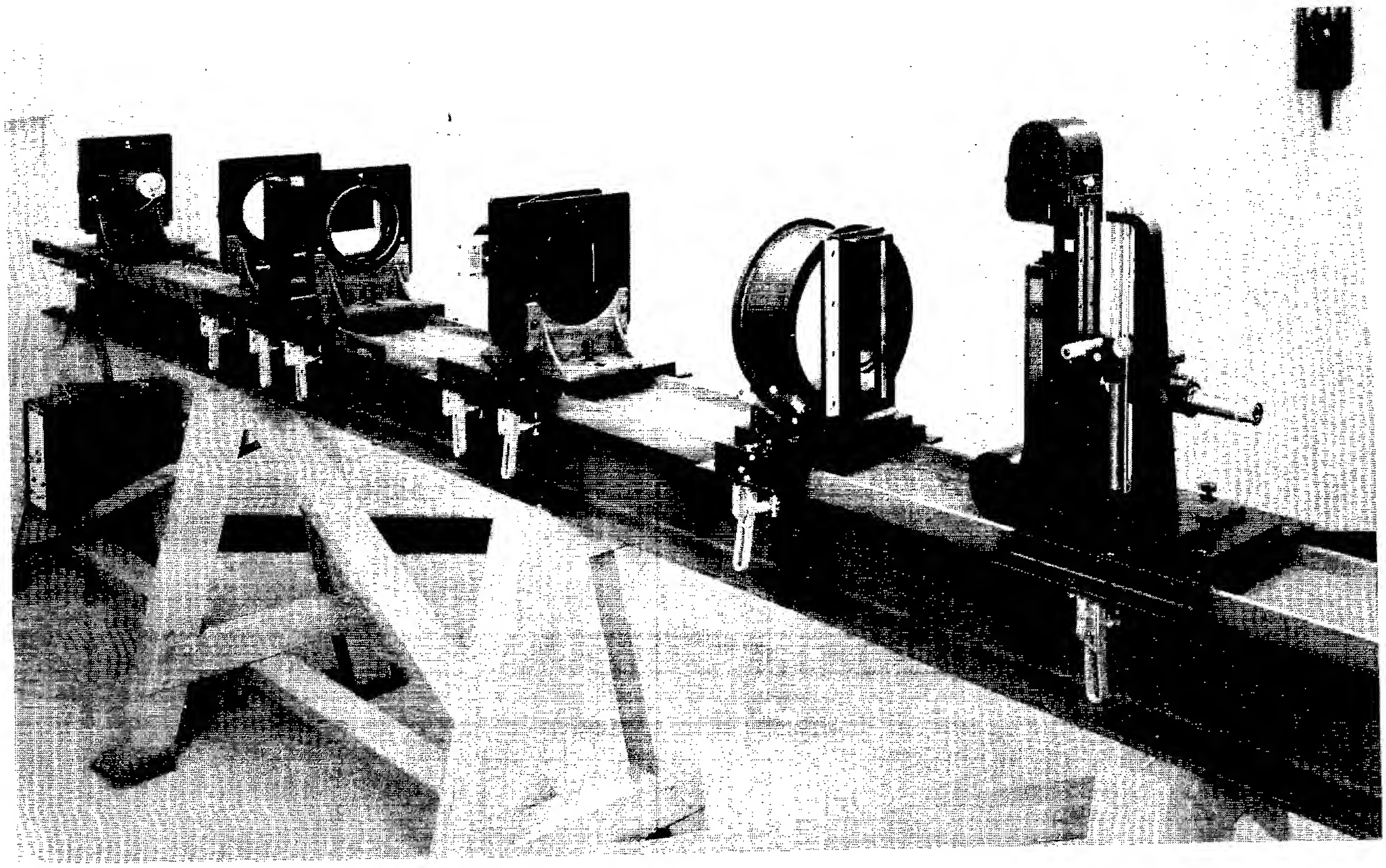
Optical Benches - Two optical benches, one of which in shown in Figure 27, have been constructed to support auxiliary work on the project. Their chief use has been for frequency analysis of the data films, although they have also been indespensable for many side experiments. One of these benches has been shipped to the field, the other will remain at Itek.

Experimental Processor - An experimental processor was built to process F101 flight test film and support investigation of new techniques. For simplicity, it was built on a frame similar to that used for the optical bench, but most of the mounts, camera, input platen, etc. are new or are redesigned to accomodate the full range interval. The unit does not contain any provision for accurate film drives. It is shown in Figure 28 with the laser in place. It has now been moved so that the carbon arc can be used as it is necessary to process the full width of F101 flight film.



OPTICAL BENCH

Figure 27



EXPERIMENTAL PROCESSOR

Figure 28

Test and Simulation - A number of simulation test films were made and used in an extensive testing program. These films and the testing are discussed in the Test and Simulation report.

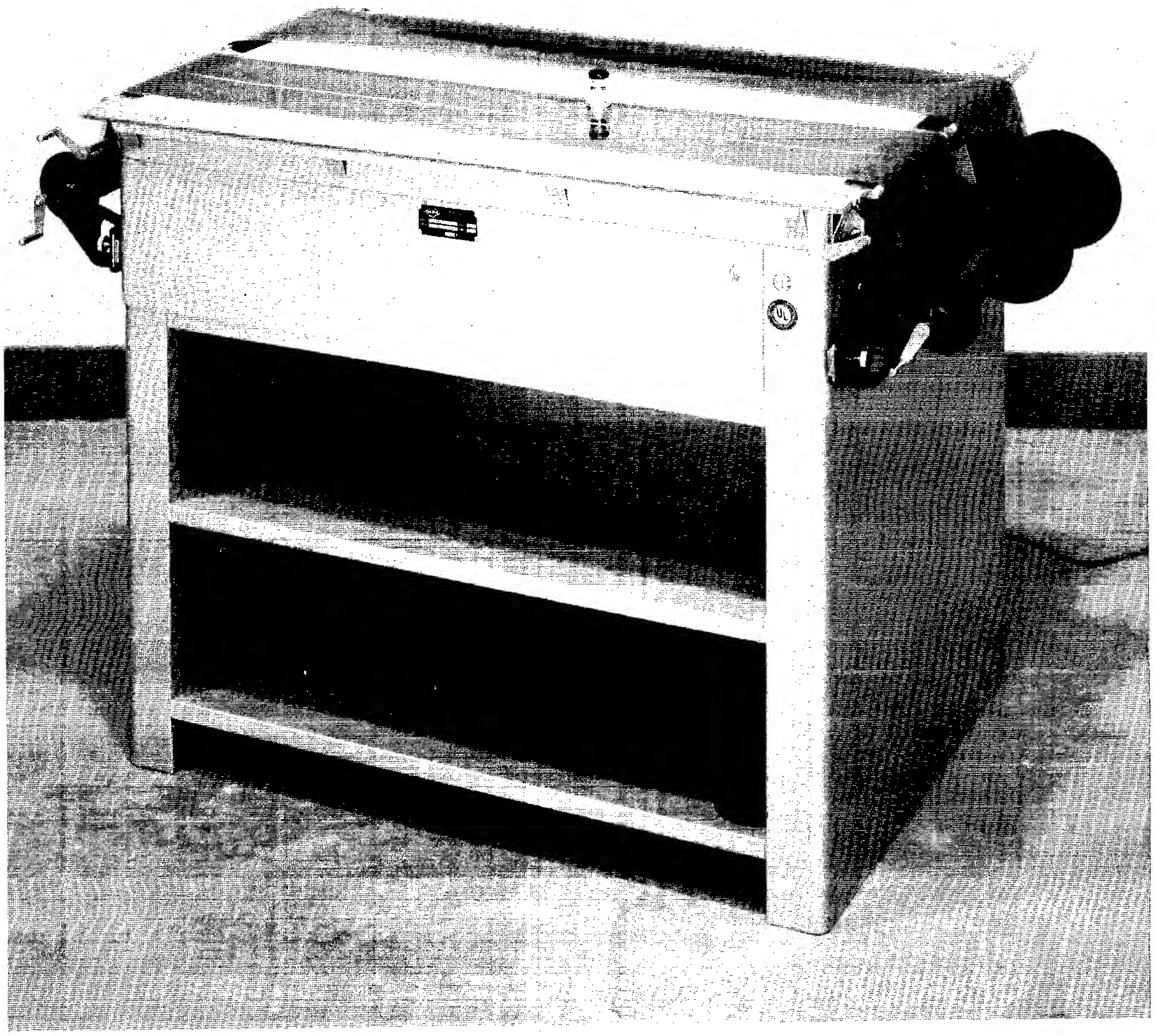
F101 Flight Test Support - The processor has been used to correlate the data made in the F101 Flight Test program. Copies of the data film and map film were made and returned to Westinghouse for their study.

System Support - The personnel on this program cooperated in system design and analysis with the Itek group working on the recorder as well as the team at Westinghouse (radar prime contractor) and the Scientific Engineering Institute (project monitor).

Field Support - Itek has assumed responsibility for the processor section at the Western site. The requirements for the rooms were drawn up, a list of standard equipment (microscopes, etc) was made, and special equipment such as the light table shown in Figure 29 was procured and modified as constructed. Engineers and technicians were trained for the field and two are currently at the site.

Drawings - A set of drawings has been maintained on the processor. Time limitations required some shortcuts (eg using layouts for assembly) during the summer of 1961, but the deficiencies have been corrected and the drawing file has been maintained up to date with all the modifications.

A set of reproducible drawings were made for delivery in 1961, but it was requested that instead of their being sent, the drawing file should be continually updated so that the reproducible set could be remade and delivered later.



LIGHT TABLE FOR FIELD USE

Figure 29

Spares - The spare parts program was completed and parts delivered with the processor.

Acceptance Test - The acceptance test was held for the processor and all associated equipment on the project during December 1963. At the completion of the tests work was initiated to prepare the equipment for delivery.

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Appendix I

APPLICABLE DOCUMENTS

Proposals

A number of proposals have been written throughout the program to support the need for additional effort. The proposals are listed here (not all proposals listed were funded).

Proposal 6B Basic proposal submitted by Scientific Engineering Institute		
Proposal 3155 Itek proposal to cover work on 6B proposal	July 1960	
Added Task Submission Change to processor necessitated by system changes. Auxiliary facilities and equipment	June 1962	SHC61-9015-157
Proposal No. 3320	August 1961	SHC-209-61
Addendum Test and Simulation Program	October 1961	SHC61-9015-271
Proposal 3334 F101 Flight Test Support	August 1961	SHC61-9015-209
Added Scope Proposal	January 1962	SHC62-9015-04
Revision New Optical System to accomodate system changes Film Drive modifications Interface Engineering	January 1962	SHC62-9015-24
Program Recommendations	June 1962	SHC62-9015-194
Added Scope Proposal Further Test and Simulation Effort Special Purpose Optical Bench Processor Continuation of F101 Flight Test Support	July 1962	SHC62-9015-215

Follow-on Proposal Installation of TV Viewing Station Continuation of F101 Flight Test Support Interface Engineering Experimental Processor Special Purpose Optical Bench for field use	April 1963	SHC63-9015-161
9015 Follow-on Proposal Field Service Test Support Correlator Modifications and Detail Correlator System Theory and Experiment Improved Correlator	March 1964	SHC64-3516-168

In addition, the following proposal was initiated in connection with this program; but it covered work concerned primarily with the recorder.

Proposal for Optimum Parameters	February 1962	SHC62-9015-38

Other documents include:

Preliminary Specification	November 1960	SHC9015-60-1R
Instruction Manual Volume I	February 1963	not classified
Instruction Manual Volume II	February 1963	SHC63-9015-102
Final Report, Test and Simulation Program (Note, this document is being partially re-written at present)	April 1963	SHC63-9015-143
Effect of Film Exposure on Recorder/ Correlator Performance (work done by R. Swing)	June 1963	SHC63-9015-544
Progress Report	November 1961	SHC61-9015-158G
Progress Report	December 1961	SHC62-9015-08
Progress Report	January 1962	SHC62-9015-57
Progress Report	February 1962	SHC62-9015-77
Progress Report	March 1962	SHC62-9015-176
Progress Report	April 1962	SHC62-9015-172
Progress Report	May 1962	SHC62-9015-195

Progress Report	June 1962	SHC62-9015-237
Progress Report	July 1962	SHC62-9015-238
Progress Report	Aug/Sept 1962	SHC62-9015-331
Progress Report	October 1962	SHC62-9015-359
Progress Report	November 1962	SHC62-9015-384
Progress Report	December 1962	SHC63-9015-42
Progress Report	January 1963	SHC63-9015-77
Progress Report	February 1963	SHC63-9015-103
Progress Report	March 1963	SHC63-9015-159
Progress Report	April 1963	SHC63-9015-190
Progress Report	May 1963	SHC63-9015-250
Progress Report	June 1963	SHC63-9015-312
Progress Report	July 1963	SHC639015-342
Progress Report	August 1963	SHC63-9015-385
Progress Report	September 1963	SHC63-9015-433
Progress Report	October 1963	SHC63-9015-478
Progress Report	November 1963	SHC63-9015-535
Progress Report	Dec/Jan 1964	SHC64-9015-81
Progress Report	Feb/March 1964	SHC64-9015-219
Progress Report	April 1964	SHC64-9015-267

APPENDIX II

Memos Concerning Parameters

The two memos reproduced here are a record of the calculations from which various parameters in the radar and correlator were set. They are included partly to present the data and partly to expand on the theoretical calculations of section III. Memo #14 is concerned with the 40,000 foot F101 tests, while #17 deals with the final vehicle at full altitude. The initial calculations, made in 1960, were necessarily based on approximate values, so that the parameters now calculated are similar to, but no exactly equal to the original figures.

The values recommended in memo #14 were not followed exactly due to limitations in the circuit modifications in the recorder for these tests. The values recommended in memo #17 have not been "officially" accepted by all concerned and may be modified slightly for actual flights.

TO: C. W. Mahon

DATE: 4 June, 1963

WJD #14

FROM: W. J. Davis

SUBJECT: System Parameters for F101 Flight Tests

The data film should have certain parameters for use in the correlator as built. This report established some of these parameters.

The correlator is designed to correlate patterns having a focal length of 149.259 inches (near) and 198.319 inches (far). The patterns at certain points on the film should have this focal length when illuminated with green (λ = 550 mμ) light. The patterns at other points should be such as to match the interference filter and keep the focal length constant.

The focal length of the pattern is given by

$$F = \frac{1}{2} \frac{\lambda r}{\lambda o} \left(\frac{v}{V}\right)^2 R$$

For our system

λr = 3.178 cm (basic data f = 9432 Mc)

λo = 550 mμ

V = 830 knots

If R is expressed in nautical miles and v in inches per second, we obtain for the center of each range

$$R_c = 2F \frac{\lambda o}{\lambda r} \left(\frac{v}{V}\right)^2$$

$$R_{nc} = \frac{2 \times 149.259 \times 5.50 \times 10^{-5}}{3.178} \frac{(830)^2 \; 72962}{v^2 \; 3600^2}$$

$$R_{nc} = \frac{20.0367}{v^2}$$

$$R_{fc} = \frac{26.6226}{v^2}$$

For the purpose at hand, it is most convenient to convert ranges to delay times which is related to the range by

$$T = 12.3643 \; \mu \text{ sec/nautical mile}$$

$$T_{nc} = \frac{247.740}{v^2}$$

$$T_{fc} = \frac{329.170}{v^2}$$

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The PRF is 1307190 ÷ 3328 = 3927.85 cps. The sweep ratio is twice that or 7855.7 cps, giving a time of 127.30 μ sec per sweep. For the high altitude F101 tests, the second time around sweep is used giving available echo times of 127.30 to 254.6 μ sec. At present, the times from 127.30 to about 133 μ sec and 183 to 193 μ sec are unavailable due to sweep details. The period after 225 μ sec or so may have weak returns due to the antenna geometry.

The sweep ratio on the data film (and on the CRT if the recorder is set at 1:1 magnification) should be such as to spread the range to match the interference filters on hand. From the interference filter drawing 9015-5049 we have the wavelength given as

$$\lambda = 550 + 20.25\,x \quad \text{(near)}$$

$$\lambda = 550 + 15.26\,x \quad \text{(far)}$$

where λ is the wavelength in millimicrons and x is the distance along the filter measured in inches. This filter was designed to go infront of the output platen in the correlator. Correcting the values to the plane of the data film gives

$$\lambda = 550 + 30.14\,x \quad \text{(near)}$$

$$\lambda = 550 + 30.24\,x \quad \text{(far)}$$

If we replace λ_o by these expressions, we obtain

$$T_n = T_{nc} \, \frac{550 + 40.14\,x}{550}$$

$$T_n = T_{nc} + T_{nc} \frac{40.14\ x}{550}$$

$$T_f = T_{fc} \frac{550 + 30.24\ x}{550}$$

$$= T_{fc} + T_{fc} \frac{30.24\ x}{550}$$

The sweep rate, expressed in inches per microsecond is

$$W_n = \frac{\Delta\ x}{\Delta\ T}$$

If $\Delta\ x = x$, then $\Delta T = T_f - T_{fc}$ and

$$W_n = \frac{x\ 550}{T_{nc}\ 40.14\ x}$$

$$W_n = \frac{13.70}{T_{nc}}$$

Similarly

$$W_f = \frac{550}{T_{fc}\ 30.24}$$

$$W_f = \frac{18.19}{T_{fc}}$$

If we choose T_{nc} at 166 μ sec, this will give a film speed of

$$v^2 = \frac{247.740}{166}$$

$$v = 1.2217$$

The total time assuming $x = \pm 2.125$ will be

$$T_n = 166 \pm 166 \frac{40.14}{550} \times 2.125$$

$$= 166 \pm 25.74$$

or 140.26 to 191.74 μ sec

Using the same recorder speed for the far range gives

$$T_{fc} = \frac{329.170}{1.2217^2}$$

$$= 220.56$$

and the extremes are

$$T_n = 220.56 \pm 220.56 \times \frac{30.24}{550} \times 2.125$$

$$= 220.56 \pm 25.77$$

$$= 194.79 \text{ to } 246.33$$

The sweep rates are

$$W_n = \frac{13.70}{166}$$

$$= .08253 \text{ in}/\mu \text{ sec}$$

$$W_f = \frac{18.19}{220.56} = .08247$$

These are nearly equal as expected. Expressed as an inverse, this gives

$$\frac{1}{W} = \frac{1}{.0825} = 12.12$$

Thus, the derived values are

film velocity = 1.22 inches/second

"sweep rate" = 12.12 μ sec/inch (average over sweep)

Event	Pulse Delay	Time from Sync	Slant range miles	Distance from edge
start of near	140.26	12.96	11.344	.437
center of near	166.00	38.70	13.426	2.562
end of near*	191.74	64.44	15.508	4.687
start of far*	194.79	67.49	15.754	4.812
center of far	220.56	93.26	17.838	6.937
end of far	246.33	119.03	19.923	9.062

* Due to sweep turnaround and optical separation, it may not be possible to record these ends of the trace.

25X1

TO: C. W. Mahon 27 February 1964

FROM: W. J. Davis

SUBJECT: Parameters for Later Tests (9015) WJD#17

This memo describes some of the parameters for later tests when the final vehicle is operating at desired range and altitude. My previous memo #14 dated June 1963 covers the current F101 tests and presumably early field tests (i. e. where V = 830 kts). I have included an appendix on non-linear sweep. This has been discussed with R. Fraser.

I have assumed that we desire to avoid a gap in the recording. I have assumed that we shift the wavelength filter to achieve this goal.

This memo only contains the results and basic equations. Most of the math is straightforward, much is contained in my previous memo. The important relationships are:*1

$$F = \frac{1}{2} \frac{\lambda r}{\lambda} \left(\frac{v}{V}\right)^2 R \qquad F = 807.14 \frac{v^2 R}{\lambda}$$

$$R = \frac{2\lambda}{\lambda r} \left(\frac{V}{v}\right)^2 F \qquad R = .001239 \frac{\lambda F}{v^2}$$

$$T = \frac{4\lambda}{c \lambda r} \left(\frac{V}{v}\right)^2 F \qquad T = .015318 \frac{\lambda F}{v^2}$$

The interference filter is described as

$$\lambda = \lambda c + mx$$

*1 See table I for definitions and units

The time across the trace is

$$T = T_c + \frac{x}{w}$$

The focal length will remain constant if

$$w = \frac{1}{mF} \frac{\lambda_r c}{4} \left(\frac{v}{V}\right)^2$$

$$w = 65.283 \frac{v^2}{mF}$$

$$= .010888 v^2 \quad \text{for } m = 40.16 \text{ and } F = 149.256$$

The ends of the trace are at Tmax and Tmin which occur at X = L and X = -L respectively. We wish to make $T_n$max and $T_f$min coincide at a point synchronized with the sweep turn around at T = 381.89.

If we assume a film velocity of 1.95 in/sec, we obtain

$$T_{nc} = 381.89 - \frac{2.024}{.0414}$$

$$T_{nc} = 333.0 \ \mu sec$$

and $$T_{fc} = 430.77 \ \mu sec$$

Thus, for v = 1.95 F = 149.256, and T_{nc} = 333

$$\lambda_{nc} = 553.8 \ m\mu$$

and for v = 1.95 F = 198.319 and T = 430.77

$$\lambda_{fc} = 539.20 \ m\mu$$

Azimuth scale factor on data film is

$$S_{ad} = \frac{V}{v}$$

Azimuth scale factor on map film is

$$S_a = 4.37 \frac{V}{v}$$

Slant range scale factor on data film is

$$S_{rsd} = \frac{\frac{c}{2}}{w}$$

Slant range scale factor on map film is

$$S_{rs} = \frac{1}{2} \frac{\frac{c}{2}}{w}$$

Depression angle θ

$$\sin \theta = \frac{A}{R_s}$$

Ground range

$$R_g = R_s \cos \theta$$

Scale factor

$$S_{rs} = \frac{dR_s}{dx}$$

$$= \frac{C}{2w}$$

$$S_{rg} = \frac{dR_g}{dx} = \frac{dR_g}{dR_s} \quad \frac{dR_s}{dx}$$

$$= \frac{d(R_s \cos \theta)}{dR_s} \quad S_{rs}$$

$$= \frac{S_{rs}}{\cos \theta}$$

If w is not constant

$$S_{rg} = \frac{C}{2w \cos\theta}$$

$$= \frac{\frac{1}{w} \; .590108 \times 10^{10}}{\cos\theta}$$

The correct wavelength is found from

$$F = 807.14 \; \frac{v^2 R}{\lambda}$$

for near range

$$\lambda = \frac{807.14 \times 1.95^2 \; R}{149.256}$$

$$= 20.563 \; R$$

For far range

$$\lambda = \frac{807.14 \times 1.95^2 \; R}{198.319}$$

$$= 15.476 \; R$$

The pertinent information is contained in the tables and graphs. Some general conclusions are:

1. The wavelength fit to a linear filter can be adjusted to be good (see table 1B) even with the non linear sweep.

2. The range scale factor changes by 20% across the range swath due to the cosine factor for ground range. It changes by 27% due to sweep non-linearity. This is superimposed on the other (see the graph) and gives a maximum variation of 37%. There is a sharp break in range scale at the break of the picture.

3. For the parameters chosen, the range scale factor is mostly less than the azimuth scale. A different set of factors (based on a slightly different film speed) would lower the azimuth curves to give a better averaging. NOTE: I am <u>not</u> proceeding to make such calculations at the present time.

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TABLE I -PARAMETERS

Symbol	Name	Units	Notes	Linear Value	Non-linear Value
V	aircraft velocity	knots	1	1870	1870
v	film velocity	in/sec	1	1.95	1.95
$\frac{V}{v}$	velocity ratio	-	1	19436	19436
λ_r	radar wavelength	cm	2	3.178	3.178
c	velocity of light	$\frac{\text{n mile}}{\mu\text{sec}}$		.161757	.161757
F_n	focal length, near	in	3	149.256	149.256
F_f	focal length, far	in	3	198.319	198.319
m_n	wavelength slope,near	mμ/in	4	40.16	40.16
m_f	wavelength slope, far	mμ/in	4	30.24	30.24
L	half length of trace	inch	6	2.024	2.024
T	pulse delay time	μsec		table IIA	table IB
PRF	pulse repetition freq.	cps	5	3927.85	3927.85
R	slant range	n miles		table IIA	table IB
λ	optical wavelength	mμ		table IIA	table IB
w	sweep velocity	in/μsec		.04140	fig A1, A2
$\frac{1}{w}$	reciprocal	μsec/in		24.15	fig A1, A2
S_a	azimuth scale factor			table IIIA	fig 1
S_r	range scale factor			table IIIA	fig 1
A	vehicle altitude	ft		90,000	90,000
R_g	ground range	n miles		table IIIA	table IB

Notes to Table I

1. These values are used for computation. In practice the $\frac{V}{v}$ will be held constant.

2. From the frequency of 9432 mc

3. These are the pattern focal lengths the correlator is designed for.

4. This is the variation of wavelength with distance along the interference filter as referred back to the data film.

5. Derived from 1307190 $\div$ 3328.

6. The 2.024 value was determined from a readjusted value of T_{nc}. The value for L could be as large as 2.064, as was used for the non-linear sweep data.

TABLE IIA

DATA BASED ON LINEAR SWEEP

Event	Pulse Delay	Time from Sync	Slant range Miles	Distance From edge	λ	Ground Range miles	Depres Angle θ	Cos θ
Near								
start	284.12μsec	29.52μsec	22.979n.m.	..538in.	472.5μm	17.576n.m.	40°6'	.76489
center	333.00	78.41	26.932	2.562	553.8	22.500	33°20'	.83544
end	381.89	127.30	30.886	4.586	635.1	27.107	28°38'	.87766
Far								
start	381.89	127.30	30.886	4.913	478.0	27.107	28 38	.87766
center	430.77	176.19	34.840	6.937	539.2	31.539	25 85	.90526
end	479.66	225.08	38.794	8.961	600.4	35.859	22 26	.92434

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TABLE IIB

DATA BASED ON NON-LINEAR SWEEP

Event	Pulse delay	Time From Sync	Slant Range	Distance From Edge	Ground Range
Start of near	285.88 μsec.	31.28 μsec.	23.121 n.m.	.498 in.	17.762 n.m.
	310.00	55.40	25.072	1.617	20.236
Center of near	332.95	78.35	26.928	2.562	22.495
	360.00	105.40	29.116	3.659	25.072
End of near	381.89	127.29	30.886	4.626	27.107
Start of far	381.89	127.29	30.886	4.873	27.107
	400.00	145.40	32.351	5.763	28.767
Center of far	427.48	172.88	34.558	6.937	31.227
	450.00	195.40	36.395	7.872	33.250
End of far	475.10	220.50	38.425	9.001	35.460

Event	Depression Angle θ	Cos θ	λ Correct	λ Used	λ Shifted
Start of near	39° 48′	.76820	475.44 mμ	470.9 mμ	
	36 11	.80710	515.56	515.9	
Center of near	33 20	.83537	553.72	553.8	
	30 33	.86110	598.71	597.9	
End of near	28 38	.87766	635.09	636.7	
Start of far	28 38	.87766	477.99	476.8	472.4 mμ
	27 13	.88920	500.66	503.7	499.3
Center of far	25 22	.90362	534.82	539.2	534.8
	24 0	.91360	563.25	567.5	563.1
End of far	22 39	.92283	594.67	601.6	597.2

Source of Entries in Tables IIA & B

Pulse Delay

A & B The end of near and start of far coincide with the peak of the triangular sweep if it is synchronized with the pulse transmitter.

A The center values are determined from T_{nc} and T_{fc} on page 2. The near start and far end are spaced by the same time.

B From the equation for non-linear sweep at the end points and intermediate points chosen from a table (not centered)

Time from sync

A & B The Pulse delay values minus the time between pulses (254.6 μsec)

Slant Range

A & B Pulse delay x speed of light/2

Distance from edge

A & B Center distance - values determined from the geometry of the Processor.

A Start and end distances, the center distance ± 2.024.

B Similar to A except ± 2.064. The intermediate values are not centered between the start and center, but are the closest ones from a table calculated for every 10 μsec

Ground Range

A & B Slant range x Cos θ

Depression Angle

A & B From Sin θ = altitude/slant range

Cos θ

A & B From tables

λ

A Center - from page 2

Ends - from center ± 2.024 x w

λ Correct

B This is the λ that should be used for each range. It is the solution of the last equation on page 4.

λ Used

B From the filter equation on page 1.

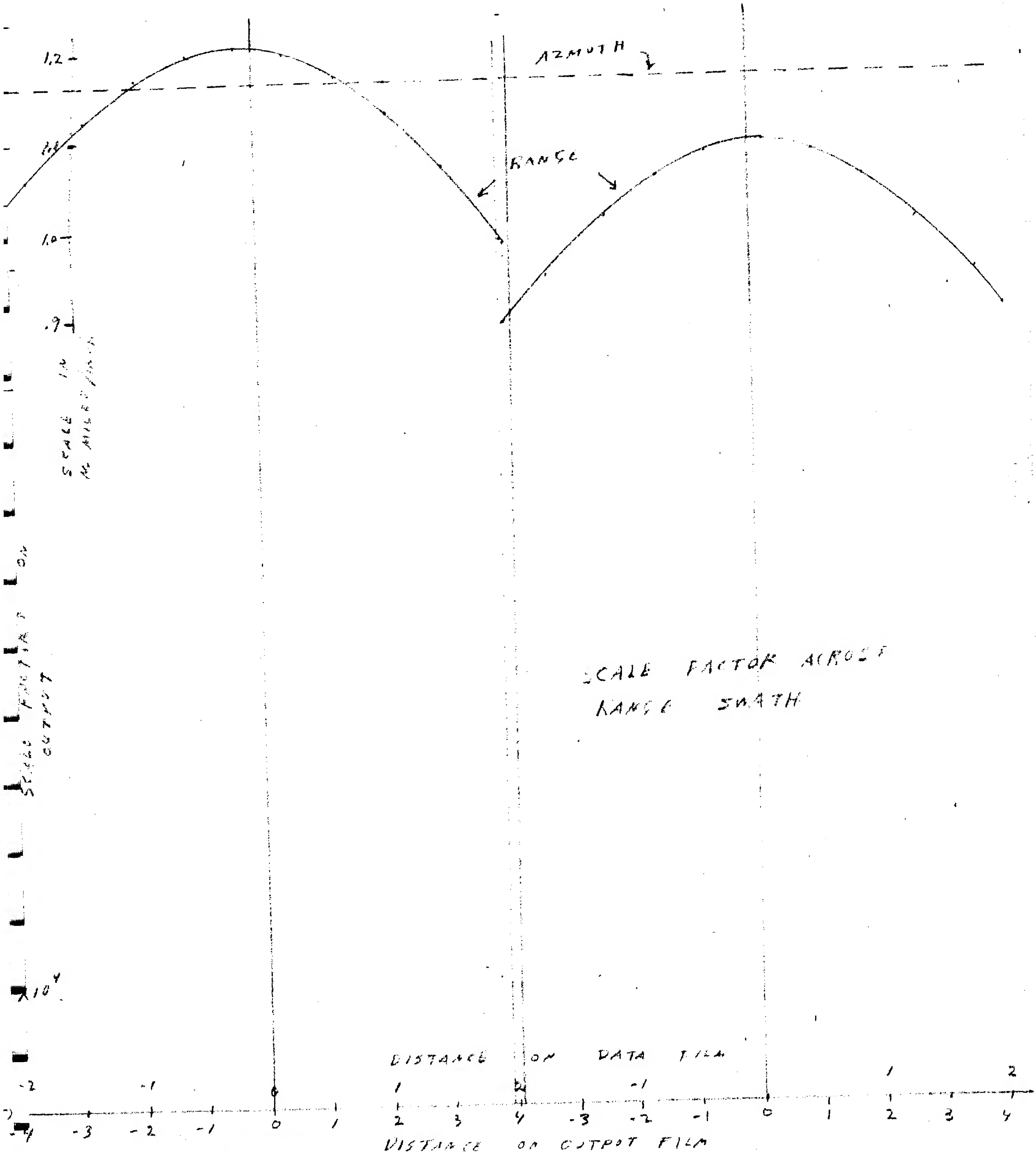
λ Shifted

B The values which result from moving the filter to cause the center wavelength to coincide with the correct value.

TABLE IIIA

SCALE FACTOR BASED ON LINEAR SWEEP

	Data Film				Map Film				
Item	Ratio	n mile / inch	ft. / .001"	.001" / 20 ft.	Ratio	n mile / inch	ft. / .001"	.001" / 20 ft.	Ratio azimuth / range
Azimuth	19436	.26638	1.6197	12.35	84935	1.1641	7.078	2.83	
Slant range	142540	1.9536	11.878	1.68	71269	.97679	5.939	3.36	
Ground range Start of near	186350	2.5541	15.529	1.29	93175	1.2770	7.764	2.58	.912
Center of near	170610	2.3383	14.217	1.41	85305	1.1691	7.108	2.82	.995
End of near Start of far	162400	2.2258	13.533	1.48	81200	1.1129	6.766	2.96	1.045
Center of far	157460	2.1581	13.122	1.52	78730	1.0790	6.563	3.04	1.078
End of far	154210	2.1136	12.851	1.56	77105	1.0568	6.425	3.08	1.101


AZMUTH
RANGE
SCALE FACTOR ACROSS
RANGE SWATH
DISTANCE ON DATA FILM
DISTANCE ON OUTPUT FILM